AD-754 971

MEMORY EFFECTS IN VISUAL SEARCH: THE GRATICULE

Joel David Chananie

Michigan University

Prepared for:

Air Force Office of Scientific Research
Advanced Research Projects Agency

December 1971

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

01
010588-[redacted]-T

HUMAN PERFORMANCE CENTER

DEPARTMENT OF PSYCHOLOGY

The University of Michigan, Ann Arbor

Memory Effects in Visual Search: The Graticule

JOEL DAVID CHANANIE

Technical Report No. 34

December 1971

108

THE HUMAN PERFORMANCE CENTER

DEPARTMENT OF PSYCHOLOGY

The Human Performance Center is a federation of research programs whose emphasis is on man as a processor of information. Topics under study include perception, attention, verbal learning and behavior, short- and long-term memory, choice and decision processes, and learning and performance in simple and complex skills. The integrating concept is the quantitative description, and theory, of man's performance capabilities and limitations and the ways in which these may be modified by learning, by instruction, and by task design.

The Center issues two series of reports. A Technical Report series includes original reports of experimental or theoretical studies, and integrative reviews of the scientific literature. A Memorandum Report series includes printed versions of papers presented orally at scientific or professional meetings or symposia, methodological notes and documentary materials, apparatus notes, and exploratory studies.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) University of Michigan, Human Performance Center Department of Psychology Ann Arbor, Michigan 48104	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

MEMORY EFFECTS IN VISUAL SEARCH: THE GRATICULE

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific Interim

5. AUTHOR(S) (First name, middle initial, last name)

Joel David Chananie

6. REPORT DATE December, 1971	7a. TOTAL NO. OF PAGES ~~99~~ 108	7b. NO. OF REFS 15
8a. CONTRACT OR GRANT NO. F44620-72-C-0019 b. PROJECT NO. AO 1949-2 c. 61101D d. 681313	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report No. 34 010588-~~01~~-T 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFOSR - TR - 73 - 0031	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Air Force Office of Scientific Research (NL) 1400 Wilson Boulevard Arlington, Virginia 22209

13. ABSTRACT

In a graticular visual search task, one in which the stimuli in the visual field remain fixed in position from trial to trial and search is required for different targets each time, the subject has the opportunity to improve his performance as he learns where to look for particular targets. A series of five experiments supported the conclusions for both letter targets or arbitrary symbols that 1) grouping stimuli in natural arrangements on the display improves speed and accuracy of target location over no distinctive grouping; 2) this improvement can be attributed at least in part to improved memory for the graticule, the stored representation of the display; and 3) the characteristics of graticular search are significant in the design of control panels in which an array of buttons are present and the subject must select an appropriate response.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Visual Search						
2. Control Panel Design						
3. Memory for Spatial Location						

THE UNIVERSITY OF MICHIGAN

COLLEGE OF LITERATURE, SCIENCE AND THE ARTS

DEPARTMENT OF PSYCHOLOGY

MEMORY EFFECTS IN VISUAL SEARCH: THE GRATICULE

Joel David Chananie

HUMAN PERFORMANCE CENTER--TECHNICAL REPORT NO. 34

December 1971

This research was supported by the Advanced Research Projects Agency, Department of Defense, and monitored by the Air Force Office of Scientific Research, under Contract Nos. AF 49(638)-1736 and F44620-72-C-0019 with the Human Performance Center, Department of Psychology, University of Michigan.

PREFACE

This report is an independent contribution to the program of research of the Human Performance Center, Department of Psychology, on human information processing stress factors, supported by the Human Resources Research Office of the Advanced Research Projects Agency, under Order Nos. 461 and 1949, and monitored by the Behavioral Sciences Division, Air Force Office of Scientific Research, under Contract Nos. AF 49(638)-1736 and F44620-72-C-0019, respectively.

This report was also a dissertation submitted by the author in partial fulfillment of the degree of Doctor of Philosophy (Psychology) in the University of Michigan, 1971. The doctoral dissertation committee was: Drs. R. W. Pew, Chairman, D. Chaffin, I. Pollack, and J. E. K. Smith.

TABLE OF CONTENTS

Preceding page blank

ABSTRACT

The visual search task is to find one or more objects embedded among a set of objects placed on a common background. A distinction was made between two aspects of visual search, random search in which each object changes position from trial to trial and graticular search in which each object remains fixed in position from trial to trial.

The salient facet of graticular search is that object fixity allows the S to develop knowledge of the objects' identities, locations, and characteristics that he uses in searching. This knowledge is defined as his graticule. An initial approach was proposed which suggested that each S develops an idiosyncratic graticule as a function of practice and uses that graticule to delineate where to look, that arrangement of objects acts to provide cues which S uses to develop his graticule, that object locations are learned differentially both within a particular arrangement, and between differing arrangements of identical objects, that visual search speed varies as a function of memory for objects' locations, and that improvement in visual search speed with practice both within a particular arrangement and between differing arrangements corresponds with the amount of learning of object locations. According to this view the finding in studies investigating display-control relationships that response time with matrix-format, pushbutton control panels was fastest on the periphery and slowest at the center of the matrix is due to inefficiencies in graticular search. This relationship was termed the response time gradient.

Five experiments were conducted to investigate the approach. The first experiment confirmed that at least a major portion of the response time gradient was attributable to search variables rather than to movement time variables. The second and third experiments showed that, with practice, performance on a display which grouped targets was superior to a display on which no grouping was provided because grouping aided memory for target location. When neutral placeholders, i.e., asterisks or empty boxes, substitute for the targets for both a grouped and an ungrouped display, Ss respond far better to the grouped placeholder display than they do to the ungrouped placeholder display. The fourth experiment replicated the prior results with arbitrary symbols rather than letters of the alphabet and demonstrated that grouping differentially affected memory for target locations. The fifth experiment examined a finding that Ss respond more slowly when performing with neutral placeholder displays. This experiment showed that this finding does not hold when the number of well learned objects displayed is well within immediate memory span.

Taken together the results suggest that the approach used, although tentative, is a useful initial attempt to explain systematically an important aspect of visual search.

Preceding page blank

CHAPTER I

INTRODUCTION

The visual search task is to find a specific object embedded among a set of objects placed on a common background. The set of objects constitutes the "ground." The figures and the ground together comprise the "visual field." The visual search task can be characterized into four different types depending upon which figure or figures move in the visual field from trial to trial: 1) all figures randomly move within the visual field from trial to trial, 2) all figures remain fixed in the visual field from trial to trial, 3) the target figure remains fixed in the visual field while the nontarget figures randomly move, and 4) the nontarget figures remain fixed in position in the visual field from trial to trial while the target figure randomly moves.

The first of these four characterizations is defined as random search because the figures move randomly within the visual field from trial to trial. The second is defined as graticular search: The figures in the visual field remain fixed across trials. Graticule is defined in Webster's Seventh New Collegiate Dictionary as "a scale on transparent material in the focal plane of an optical instrument for the location and measurement of objects." Only random search and graticular search are considered in this paper because these two characterizations of visual search allow a worst case analysis. Once the worst cases are analyzed and understood, the solutions to the intermediate cases should be straightforward.

The distinction between these two tasks is exemplified by finding the price of a given stock in a scrambled listing (random) versus an

alphabetical listing (graticular) or by learning to operate a typewriter with a keyboard which is scrambled from moment to moment (random) as compared with a fixed keyboard (graticular). The salient aspect about graticular search is that since the visual field is stable, repeated search allows S to learn where objects are located. The map of a visual field a subject develops and stores in memory is defined as the graticule. The dictionary definition of "graticule" does not refer to the nature of the objects in the visual field; rather it refers to an instrument for locating objects. The distinction between random and graticular search then is based not on the nature of the objects in the visual field, but on the existence of a stable visual field which permits the S to develop a graticule (as defined by the author). While the ground could conceivably vary from trial to trial, typically in applied situations it does not and so this aspect of search will not be discussed further.

The purpose of this dissertation is to extend work in visual search by initiating studies of graticular search, a heretofore neglected aspect. While virtually all research on visual search has been done for random search and none for graticular search, we may review the major findings for random search as a starting point for thinking about graticular search.

The visual field itself may vary in many respects: area, number of objects, object similarity, and geometric patterning versus random patterning of objects. The chief findings for random search are the following: search time increases with the number of candidates to be examined (Green, McGill, & Jenkins, 1953; Green & Anderson, 1956; Baker, Morris, & Steedman, 1960; Smith, 1961); when display area and number of objects are confounded, both the number of eye fixations and the average

interfixation distance increase with increases in display area, while average duration per fixation decreases (Enoch, 1959; Baker, Morris, & Steedman, 1960); and search time increases with target-nontarget similarity (Smith, 1961; Gould & Schaffer, 1965; Gould, 1967). Geometrical patterning versus random patterning has not been investigated.

The effects of target cueing have also been studied in the random search paradigm. The main cue used to aid _Ss_ has been color coding. The finding here is that somewhat informed _Ss_ find targets faster than uninformed _Ss_ (Green, McGill, & Jenkins, 1953; Green & Anderson, 1956; Smith, S. L., 1962), but this finding is not without its complications. Green and Anderson's _Ss_ searched displays for two digit targets under three conditions: 1) all numbers were the same color, 2) _Ss_ were ignorant of the target's color when two colors were displayed, and 3) _Ss_ were informed about the target's color when two colors were displayed.

For these three conditions, search time was an increasing function of the number of symbols that were the same color as the target. However, the color specified condition was always slower than the single color condition, and the color unspecified condition was always slower than the other two.

Thus, regardless of whether or not they knew the target's color, _Ss_ did not ignore the presence of the other color on the display, i.e., they did not completely filter irrelevant information. S. L. Smith (1962), in a similar experiment, did not replicate this finding. The issue is important because it ties in with experiments designed to discriminate between serial and parallel processing models for reaction time. Egeth (1966) found that _Ss_ did not completely filter information that was irrelevant to their present task.

Williams (1966) examined the effect of specifying target color, size, and shape singly and in combination, on S's eye movements and search times when searching for two digit targets. He found that Ss who were provided with color information used it rather than size or shape information. When color information was not provided, Ss used both shape and size information. Thus, Ss impose a preference ordering on cues when several are available to them.

The picture which emerges from these findings is the following: Ss require increasing amounts of time to find a target as the number of possible candidates to be examined increases and as the similarity of targets and nontargets increases. In order to accomplish the task, they look more quickly, more often and over a wider area per look. When they are given cues about the nature of the target, Ss use the cues to find the target more quickly, but additionally they impose a preference ordering on cues when several are available to them.

Let us now briefly adopt the language of information theory to discuss the effect of cueing. If we regard each object in the visual field as a message with a nonzero probability of occurrence and the aggregate as a message set, then S's average uncertainty about the message set increases with the number of possible messages. The effect of a cue is to reduce the size of the message set the S is considering, i.e., the cue allows the S to partition the total message set into two sets, one relevant and one irrelevant, and thereby to reduce his total uncertainty. A cue thus acts as a rule which S can use to partition the total message set to reduce his average uncertainty. Ss prefer and/or are more able to use some rules than other rules.

No parallel analysis of either the visual field or of the effects and limitations of cueing has been done for graticular search. However, some literature which can be related to graticular search comes from a series of studies investigating display-control relationships (Garvey & Knowles, 1954; Garvey & Mitnick, 1955).

These studies used pushbutton control response panels on which the pushbuttons were arranged in _n_ rows and _n_ columns (8 or 10). The rows were labeled alphabetically on the side, and the columns were numbered at the top. The pushbuttons were unlabeled. The _S_'s task was to press a designated pushbutton upon command. This task can be partitioned into two parts: 1) to find the designated pushbutton; and 2) to depress the pushbutton. The first part is clearly a graticular search task since the pushbuttons and their labels remained fixed from trial to trial. No controls were incorporated in either study for the distance moved by the hand.

Garvey and Knowles (1954) showed that when pushbutton controls were arranged in a matrix, response time was shortest for those pushbuttons located on the periphery. Furthermore, for any row or column of the matrix, response time increased from either end toward the center of the row or column. These statements are a gross characterization of the relationship, since there were local minima in the curves. The phenomenon of increased response time toward the center of an array will be referred to as a response time gradient.

The importance of the response time gradient for visual search is that the gradient disappeared when some lines were added to an 8 x 8 control panel but reappeared when more lines were added, suggesting that the _Ss_ used the lines to partition the visual field when searching for a

target. One set of two lines partitioned the panel into four equal quadrants, another set of six lines partitioned the panel into 16 equal segments, and a third set of four lines partitioned the panel into four segments of four pushbuttons, four segments of eight pushbuttons, and one central segment of 16 pushbuttons. The response time gradient disappeared equally with each of these partitionings. An 8 x 8 partitioning restored the gradient. Further, the partitioning which restored the gradient increased response time such that it was equal to response time in the condition where no lines were present at all (Garvey & Mitnick, 1955). A similar finding on the effects of number of cues has been found in a time reading task in which Ss read the time from a pair of pointers alone or with cues provided singly and in combination (Zeidman & Lyman, 1963; Groth & Lyman, 1961).

The response time gradient may be either a perceptual effect or a motor effect, i.e., it may result from processes in finding the pushbutton or from processes in pushing the pushbutton. With the matrix response panel, a gradient, as a motor effect, may have resulted simply because a subject moves more slowly when concerned about pushing the wrong response button. By this analysis, buttons on the extreme periphery, being easily accessible from one direction, would be less subject to inadvertent responses and hence would show the fastest response times.

The evidence against the response time gradient as entirely a motor effect is that adding some partitioning lines enhanced performance, but adding too many lines degraded performance. Since the same responses were executed, motor variables cannot account for the gradient's appearance and disappearance. The effect of partitioning lines on response time implies that Ss were using the lines to find the pushbuttons.

Models explaining the response time gradient must therefore consider more central processes dealing with the flow of information.

The central issue in the study of graticular search is to delineate the processes that Ss use in locating a target. The response time gradient suggests that fixed target locations permit the learning of particular locations of the array at different rates. These resulting memory differences are reflected in the longer times to locate the target positions that have been acquired less firmly.

From an intuitive standpoint, many variables might affect the rates of learning object locations: object differences such as size, shape and brightness; visual cues such as lines, spaces and color; differing geometrical arrangement of the objects in the visual field; and the labeling of the objects with an unordered, partially ordered, or completely ordered set of labels. The effect of geometric arrangement of identical targets has been chosen as the major independent variable in this research because arrangement of targets in a stable visual field seemed to the author to be the single most important variable for understanding graticular search.

If we accept arrangement as the crucial variable, then we can ask what we expect the effect of arrangement to be. From previous research on random search and display-control relationships the results most salient for graticular search are the effects of cueing and the response time gradient. We previously noted that providing Ss with cues about the nature of the target could be interpreted as providing Ss with rules for partitioning the visual field, thereby reducing his subjective uncertainty about where to look. We might then expect that the effect of arrangement would be to provide one or more cues for partitioning the

visual field. We also noted that the response time gradient suggested that fixed target locations permit the learning of particular locations of the array at different rates. Thus, within a given arrangement of objects in a stable visual field, we would expect that target locations would be learned at different rates. In addition, if arrangement provides cues which suggest rules for partitioning the visual field, then we would expect that since Ss find some cues more useful than others they would find some arrangements more useful than others. These differences in usefulness would be reflected as differences in average search time.

A cue is useful only insofar as someone uses it. If arrangement provides cues for partitioning the visual field in graticular search, then in order to understand the effect of arrangement we need to develop a description of what S does in a graticular search task. A tentative approach we can adopt to initiate studies in graticular search is to suppose that S learns and remembers the identities, characteristics, and locations of objects located in the visual field as a function of practice. The alternative, of course, is that the knowledge is mastered at once and that subsequent improvement in performance with practice results from learning how to look rather than where to look. Under the supposition we have adopted, the learning of both where and how to look are considered continuous functions of practice. We will refer to this knowledge as the graticule. Each S develops his own graticule for each visual field based in part on his past experience and habits and in part on the perceptual properties of the visual field. As he gains increased experience with a particular stable visual field and learns

more about it, the S will adjust his graticule from initial gross representations to finer representations.

When he wants to find a particular object, S uses his knowledge about that object and the visual field to ascertain where to look. At least four cases are distinguishable: S's state of knowledge about the display could be partial or complete and his strategy of knowledge utilization could be to use all available knowledge or to use some available knowledge. Consider, for example, 27 objects arranged in groups of three into three columns and three rows. S would have complete knowledge about the display if he knew each object's identity, its row, its column, and its position (left, middle, or right) within its group. If, however, S knew anything less his knowledge would be partial. For each state of knowledge S could use all he knew about an object or only some of what he knew in looking for it. He might then randomly search within a row for an object because he remembered only which row was appropriate or because he felt that this was as quick a way as any to find it. The situation becomes more complicated, however, because for each of these cases S can alternate looking with using his knowledge. As an example, suppose that S knows an object's row and column. He could begin looking at one end of the row, remember the object belonged to the column at the other end, subsequently look at the other end; or he could initially remember both the row and column information and consequently look there immediately. In both instances S would completely utilize his partial knowledge, but the behavior exhibited would be quite different and would require different amounts of time to complete.

Despite this additional complication we would expect in general that the more S knows about the visual field the better he will be able to locate specified targets. Thus, when S is uncertain about the visual field the search strategy he uses will be relatively crude but when he is more knowledgeable about the visual field the search strategy he uses will be more precise. We could then expect certain things: a) that when S is uncertain about the target location he will use his partial knowledge to delineate an area of the visual field in which to look and will then scan for the target. At this point we will assume that the scan is a random search process within the delineated area. b) That the number of eye movements necessary to locate a target will decrease as a function of practice because S, with more knowledge about the visual field, will know more precisely where to look. c) That Ss may use cues such as lines, spaces, and color as aids in looking, d) that there may be a trade-off between being able to partition a visual field more finely and a buildup of difficulty in remembering the partitions, and e) that the way S looks for a particular target might become increasingly automatic in the development of a motor skill.

One comment about the foregoing approach to graticular search is in order, and that is that we presently know nothing and the approach specifies nothing about how S sets up a graticule, what information he stores in the graticule, how he organizes the structure of the graticule, or how he processes the graticule once he has set it up. These are entirely open problems.

While the foregoing approach is speculative, the results from the display-control experiments cited earlier can be explained by the concepts we have developed. Given a linear array of objects in the visual

field without spatial demarcators, each S partitions the array and then scans within the selected partition. Let us assume that some Ss partition the first and last objects of the array from the remainder, that other Ss partition the first two and last two objects from the array, and so on, and that the middle partition contains more objects than does any other partition. Response times for the end objects are fast since there are few objects to examine, while response times for the middle objects are an increasing function of the number of objects examined. The response time gradient, while evident in individual Ss, emerges most strongly when all responses are averaged over all Ss.

As they gain more experience with the array, Ss develop better graticules and techniques for partitioning the array more effectively. They thereupon decrease the number of objects examined, and so reduce their overall response time. Spatial cues such as lines or spaces aid the Ss in developing better graticules and partitioning techniques.

The operator's memory, however, gradually limits the beneficial effects he realizes from additional spatial cues. Adding more spatial cues yields better segmentation in principle, but the operator may choose to handle his memory problem by using a simpler partitioning, i.e., fewer sets with more members per set, and scanning more. His using a simpler partitioning increases the number of objects per partition, which in turn increases scan time to find a target and restores the gradient for him. Individual differences between operators in both the approach of memory saturation and in the number of objects that can be held per partition are expected; when response times are averaged over operators, the gradient is restored. How far the memory limit can be extended with additional practice must be tested for various operators and displays.

Summary

Two characterizations of visual search, random search and graticular search have been distinguished. What little related literature exists has been reviewed, but since this dissertation is proposing a new approach and area of research, relevant literature is scarce. Certain experiments in display-control relationships have been classified as instances of graticular search. The effects of partitioning lines on the control panels require that approaches purporting to explain the response time gradient consider central processes dealing with the flow of information. Such an approach was then suggested. The approach is based on the assumption that the *S* develops a mapping of the visual field which he references to partition the field. The results of the display-control experiments can be understood within the framework of this approach.

If the approach is viable, then certain hypotheses become reasonable. Specifically the following should be shown: 1) A response time gradient can be obtained in a search experiment in which motor effects have been avoided, 2) Partitioning the visual field should yield superior performance over a visual field which has not been partitioned, 3) A display yields superior performance *because* it aids memory for target locations, and 4) Partitioning the visual field differentially affects the strength with which object locations are learned. The experiments which follow were designed to these hypotheses.

CHAPTER II

EXPERIMENTS

Five experiments were conducted to investigate the usefulness of the approach. The approach suggests that the operator searches memory one or more times to determine the appropriate area on the panel in which to look, and then looks for a desired target. In particular, the approach suggests that the response time gradient is due to the result of a memory process and is not strictly due to motor variables. The first experiment shows, indeed, that the gradient can be obtained when movement time variables have been controlled. The second experiment examines the prediction that, with practice, performance on a display which groups targets is superior to a display on which no grouping is provided. The third experiment shows that the grouped display yields superior performance because it aids memory for target location. When neutral placeholders, i.e., asterisks or empty boxes, substitute for the targets for both a grouped and an ungrouped display, _Ss_ respond far better to the grouped placeholder display than they do to the ungrouped placeholder display. The fourth experiment extends these results to arbitrary symbols rather than letters of the alphabet. It also demonstrates that grouping differentially affects the strength with which symbol locations are learned. The fifth experiment examines a finding that _Ss_ respond more slowly when performing with neutral placeholder displays than when performing with the usual displays. Experiment V shows that this finding does not hold when the number of objects displayed is well within immediate memory span.

Experiment I

The purpose of Experiment I was to obtain a response time gradient in a visual search task under conditions which avoid movement time variables. The S's task was to read a letter in a warning box, find that letter on the display, and press one of two response keys to indicate whether a dot had been placed either above or below the target letter. Response time was the dependent variable.

Subjects

Two Ss were run, the author (DC) and a laboratory technician (RG). Each S had 20/20 corrected vision.

Apparatus

A Digital Equipment Corporation PDP 7 computer was used to control a Model 340 cathode ray tube. The cathode ray tube was 14 in. in diameter, and tilted back 20 degrees with respect to vertical. A two-key response box was employed. Ss were seated approximately 18 in. from the cathode ray tube.

The display was a semicircular array of English capital letters. The order of the letters was alphabetical, except for the omission of M and V (see Figure 1). Both the distance between letters and the distance from each letter to the warning box position were constant. Each letter was 3/8 in. tall and 5/32 in. wide. A dot appeared 3/8 in. above or below each letter. The display was sufficiently bright for easy visibility. The average distance of the letters from the warning box position was 3.8 in. The computer selected the target for each trial within the constraint that each half of the alphabet was sampled equally often.

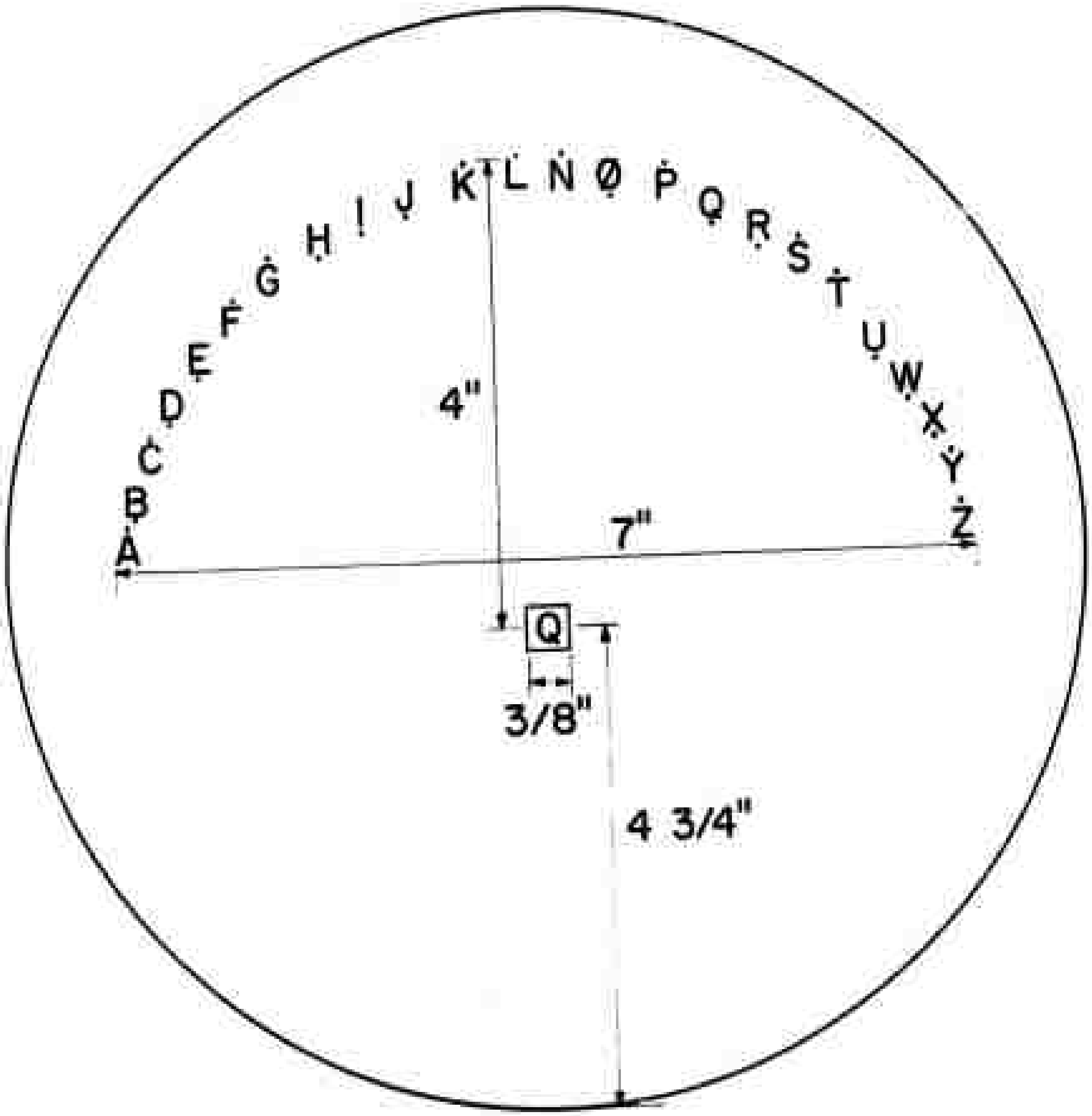

Fig. 1. Display S for Experiment I.

Procedure

There was a dot above or below each letter on the display. The dot positions were assigned randomly to the letters by the computer on each trial. S's basic task was: to read a letter in a small box on the cathode ray tube; to find the position occupied by that target letter on the display; to determine whether the dot position for that target for that trial was above or below; and to press the appropriate response key. The mapping of dot positions to response keys was constant and the same for each S. Prior to each trial, the S positioned the index finger of each hand on the response keys. The Ss were instructed to respond as quickly as possible while performing at no more than a 5% error rate.

On each trial, a warning box appeared below the array. Two seconds later the target letter appeared in the box, and simultaneous the randomly placed dots came on the screen. The target letter, the warning box, and the dots terminated after S responded, or 3 sec later, whichever came first. The warning box came on again 2 sec later to begin another trial. Three hundred and sixty trials in six blocks were run per day for 10 days. Ss were informed of their total number of errors and average correct response time at the end of each block. Response omissions were scored as errors.

Results

Both Ss responded within the instructed error rate. Overall, Subject DC made 1% errors and Subject RG made 3% errors. Errors were evenly distributed across letters. The response time results are presented in Figures 2 and 3, which plot mean response time over letter positions. The upper curve in each graph presents the means over the first five sessions, and the lower curve presents the means over the

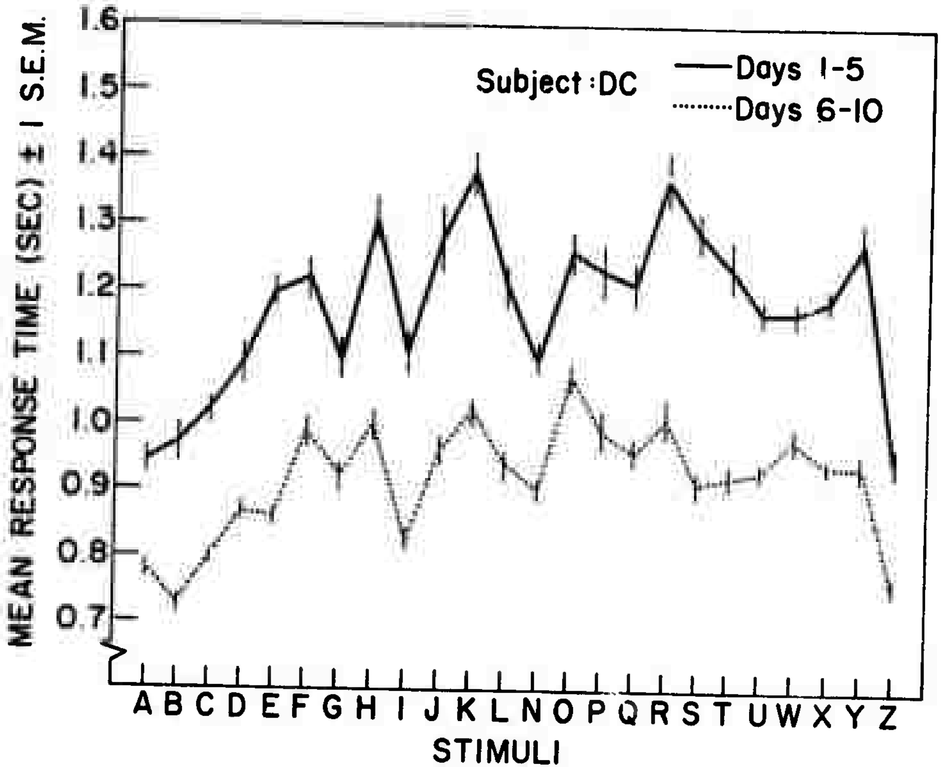

Fig. 2. Mean response time over letters.

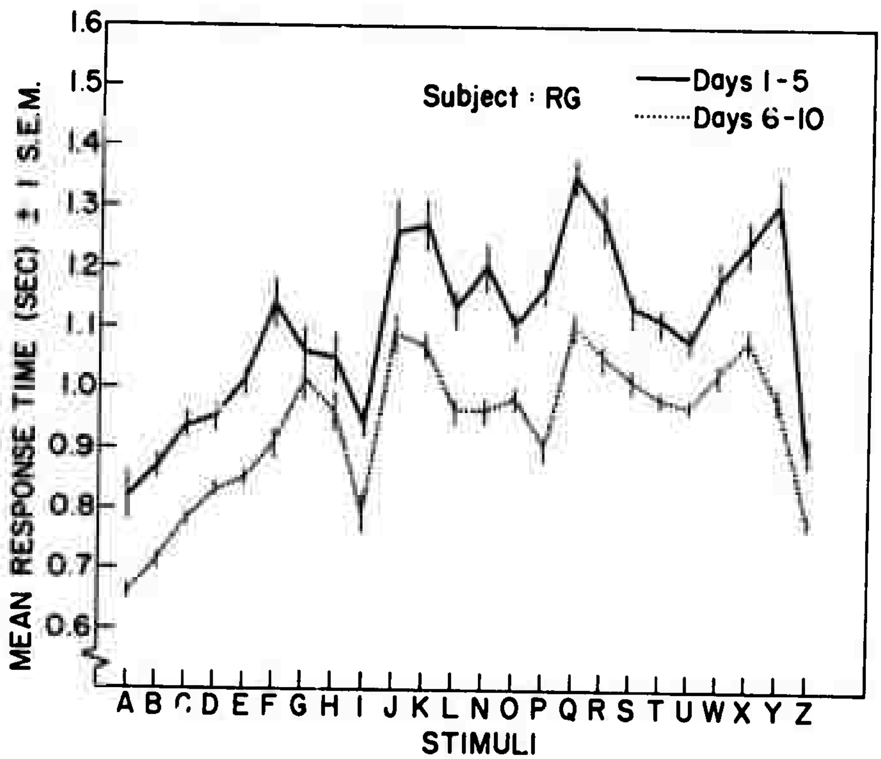

Fig. 3. Mean response time over letters.

last five sessions. Within each S, the shape of the curves is quite similar. The vertical bars represent plus and minus one standard error of the mean. The mean response times of both Ss within a session rarely differed by more than 0.1 sec.

The graphs indicate that response time for the ends of the array is, in general, faster than response time for the middle of the array. Response time is particularly fast for the early part of the alphabet, where the trend in response time appears almost linear, especially for Subject RG. For both Ss the slopes of the curves for the first six letters are in the range of 40 to 50 msec per item; the slope values do not appear to change with practice. These figures are consonant with scanning rates found in memory search tasks (Sternberg, 1966) and suggest that S uses letter order to find the first six targets. It is reasonable to conclude from these graphs that the response time gradient is not due only to movement time variables, since the gradient has been obtained using a search task in which movement time variables have been controlled. This is the first experimental demonstration anywhere of this finding.

Idiosyncratic differences between the Ss with respect to individual letters are also quite noticeable. Although the grand mean for the data for Days 6 to 10 was the same for both Ss, $\overline{RT}$ = .93 sec, the standard deviations of the means of the individual letters about the grand mean were 0.04 sec for Subject DC and 0.14 sec for Subject RG. Both Ss responded more slowly to the second half of the alphabet than they did to the first half, but the difference between the average of the means between the first and second halves of the alphabet was 0.05 sec for Subject DC but 0.10 sec for Subject RG. Thus, while both Ss had the same overall

average response time, the manner in which they responded was somewhat different.

This difference supports the approach's contention that given the same stimulus configuration, Ss can and do develop graticules. The idea that Ss have graticules gains plausibility from the fact that the physical distance of each letter from the warning box was constant, so that the difference in average response time between the two halves of the alphabet cannot be explained on the basis of the minimal eye movement distance. Perhaps the Ss required more eye movements on the average to find a target in the second half of the alphabet. But the reasons are associated with the individual Ss, and not the display.

Experiment II

The purpose of Experiment II was to examine the effect of grouping targets. The prediction was that average response time after practice with a grouped display would be less than average response time with an ungrouped display. The independent variable was geometric arrangement of the target letters, and the dependent variable was response time.

The approach states that Ss reference their graticules to ascertain where to look in the visual field, and that they modify their graticules and ways of looking as a function of practice. If arrangement acts as a cue to provide aids for partitioning the visual field, then we would expect that just as Ss find some cues more useful than others they would find some arrangements more useful than others. These differences in usefulness would be reflected as differences in average search time. In particular, a grouped display should provide more cues for Ss to use as they learn more about the display, thereby enabling each of them to develop a more precise graticule and technique for looking. By

partitioning more efficiently the S directs his eyes to a smaller group of objects. Since fewer objects need be examined, he saves time and the net effect of these savings over trials is to reduce mean response time.

Subjects

Two Ss served, one for seven sessions (DG), and one for 10 sessions (TM). They were draftsmen supplied by a contractor, and they performed as part of their regular duties. Each reported his sight as 20/20.

Apparatus

The presentation and timing apparatus employed was the same as in Experiment I. Two displays were used. The first, denoted by S, merely arranged the letters of the alphabet in order (except M and V) along an arc. This was the same display used in Experiment I. The second display, denoted by P, arranged the letters as is shown in Figure 4. Since no algorithm exists in the literature for partitioning a visual field to minimize average response time, the layout used was chosen purely on the basis of experimenter intuition. This particular physical partitioning divided the visual field into a left and a right half and subdivided the halves into three rows. Further, no group of targets contained more than three items. This number is well within the maximum number of items per partition used in the Garvey and Mitnick (1955) experiment. The letter sizes and distances of the dots from the letters were the same in both displays. The average distance of the letters from the warning box was 3.81 in. for Display S and 3.76 in. for Display P.

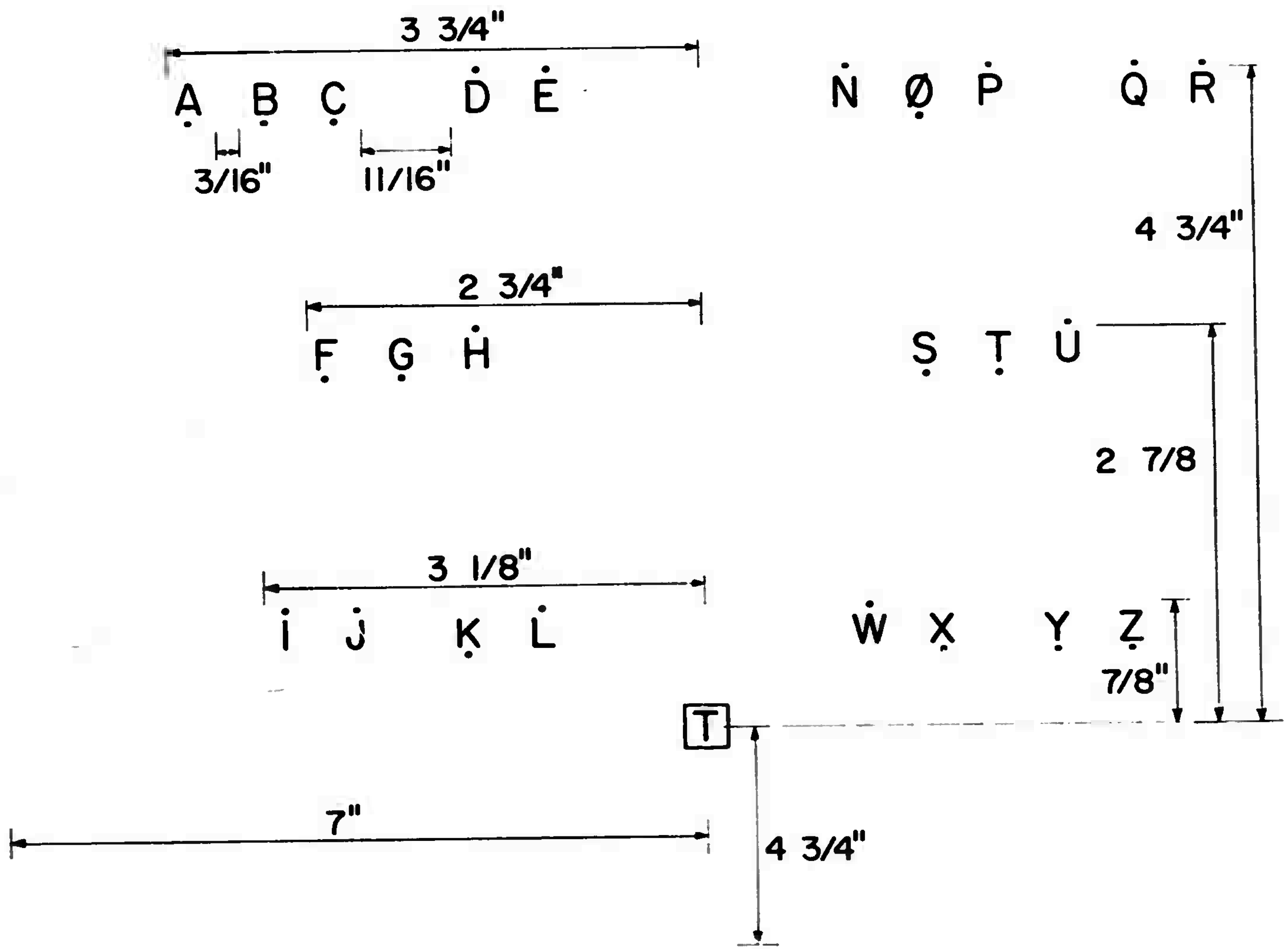

Fig. 4. Display P.

Procedure

The only difference in procedure between Experiment I and Experiment II was that Ss in Experiment II ran four consecutive blocks of trials on each display per day. Thus, on each session the subject gave 240 responses for each display. The order of display administration was balanced within each subject over the experiment. The experimental sessions lasted 2 hr, with a 20-min break between the presentation of the two displays.

Results

Each S performed at a 1% error rate on each display. The response time results are shown in Figures 5 and 6 which plot mean response time over sessions for both displays. The vertical bars represent plus and minus one standard error of the mean. These graphs show the development

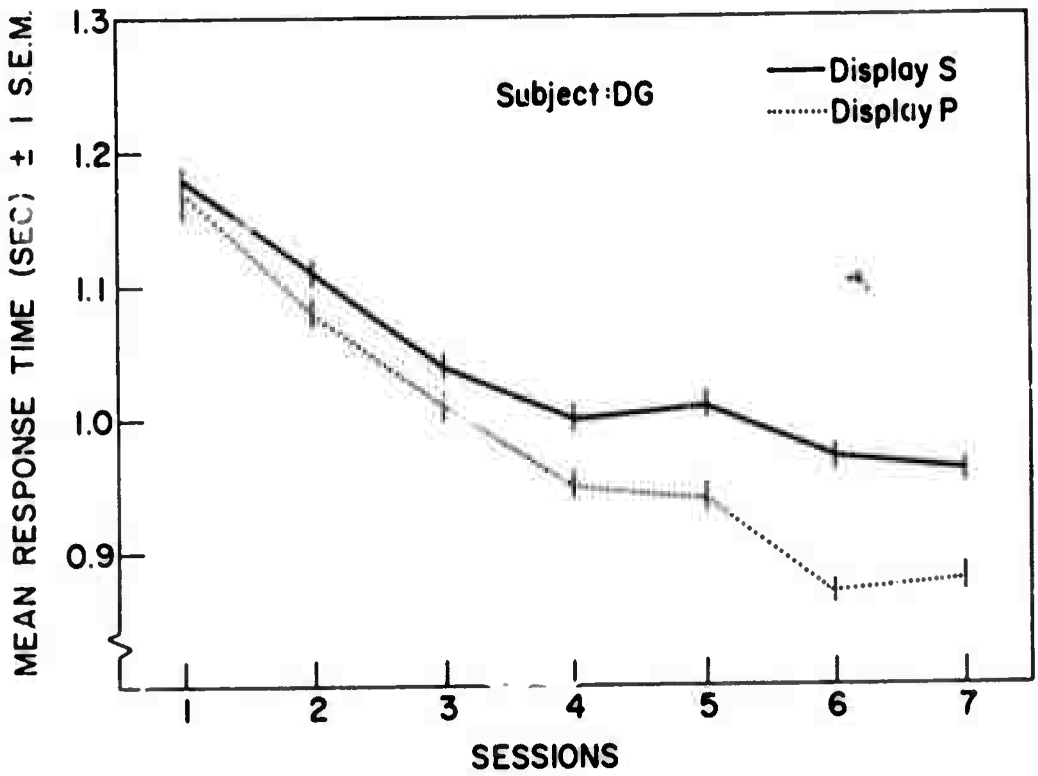

Fig. 5. Mean response time over sessions.

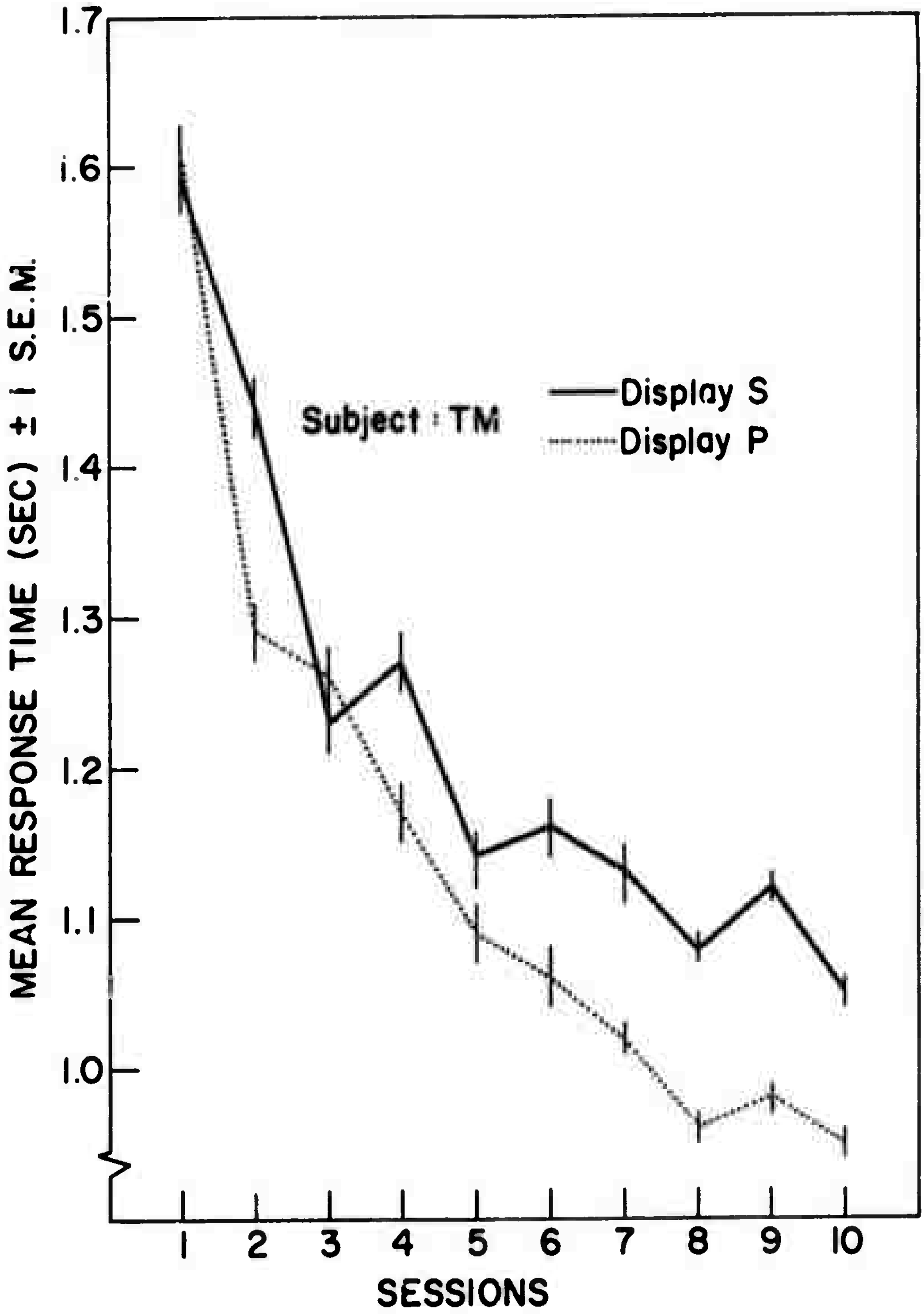

Fig. 6. Mean response time over sessions.

of the clear superiority in performance on Display P over performance on Display S. A separation of more than two standard errors between two means is equivalent to a t test which is significant at the 0.05 level.

For the last two days of practice, each S gave a mean response about 100 msec faster to Display P than to Display S. If we minimally estimate by order of magnitude the time to read the letter in the warning box at 100 msec, the time for one eye movement at 10 msec, the time to ascertain whether the dot was above or below the target letter at 100 msec, and the time to press the response key at 150 msec, then we can estimate the time to reference the graticule for eye movement instructions at 500-600 msec. In relation to this number, a difference of 100 msec between displays is reasonably large.

While both Ss responded faster on Display P, Subject DG did not significantly improve on either display during this last two days of practice, while Subject TM apparently was improving at least on Display S on his final day. Overall, Subject DG responded more variably to individual letters on Display P than on Display S, while Subject TM did not. The standard deviation of the individual letter mean response times about the display mean response time was 0.06 sec on Display S and 0.16 sec on Display P for Subject DG ($F_{23,23} = 7.11$, $p < 0.05$), but 0.10 and 0.11 sec respectively for Subject TM ($F_{23,23} = 1.21$, n.s.).

While the mean distance of the letters from the warning box was about equal for both displays, no two letters between the two displays were at an equal distance. If, however, the letters across displays whose distances differed by 0.2 in. are examined, some rough notion of the effect grouping had on search is obtained. These letters were F, G, T, and U. The results are mixed. Subject DG was faster on F and G on

Display S and faster on T and U on Display P. Subject TM was faster on F on Display S and faster on G, T, and U on Display P. The only firm conclusion from this analysis is that both Ss were faster on Display P to letters late in the alphabet.

Two-way analysis of variance with one observation per cell of the letter mean response times on Display P for the last two sessions revealed significant differences ($p < 0.05$) between subjects, letters, and groups within letters (see Table 16 in the Appendix). Linear contrast analysis of the groups within letters variable showed that Ss responded faster to the right half of the display, and showed no difference in mean response time between the two and three letters groups. There was, however, a significant difference between the rows of the display. The row nearest the warning box showed faster response times ($\overline{RT} = 0.87$ sec) than did the other rows ($\overline{RT} = 0.96$ sec). Thus, mean response time for letter groups did not vary as a function of the size of the letter group, but did vary as a function of the distance of the group from the warning box.

This result may have been due to the difference in physical distance the eye need traverse since the first row was close to the warning box, or it may have been that Ss searched for a target in the further rows after they checked to see if the target was in the first row. The latter argument seems implausible. If Ss checked the first row on their way to the second or third row, then it seems equally likely that they would check the first two rows on their way to the third. This double check would result in orderly differences between the rows, but the data showed no differences in mean response time between the second and

third rows. However, if Ss only used a single check strategy the obtained data could have resulted.

The former argument seems the more likely explanation of this result. Ss may sometimes have used peripheral vision to examine some letters in the lower row while they were looking at the warning box and consequently reduced their average search time. Assuming a viewing distance of 18 in., the distance to the farthest letter in each row was approximately 10, 12, and 18 degrees from the warning box, while the distance to the nearest letter in each row was approximately 5, 12, and 15 degrees. These figures are for the nearest, middlemost, and farthest rows, respectively. The range of 5 to 10 degrees of visual angle for the nearest row is not too discrepant from the 3 degree figure usually adopted for foveal vision, and so it is not unreasonable that Ss could process some information from the nearest row while foveally examining the warning box.

Experiment III

The approach being tested suggests why the grouped display in the previous experiment produced significantly faster response times: With practice the operator gradually improved his memory for target location on the grouped display. If this explanation is correct, the S's memory for symbol locations can be tested by removing the symbols from the display and substituting neutral placeholders such as asterisks to mark their spots. It is assumed that Ss must rely on memory in order to perform the dot judgment task consistently at better than chance accuracy. The prediction is that interrogating memory with this technique at different stages of practice should show a) simultaneous improved performance on the memory task and improved performance on the normal

task, and b) superior performance with the grouped placeholder display over the ungrouped placeholder display. The two independent variables were 1) geometric arrangement of the letters, and 2) letters present or absent; response time was the dependent variable.

Subjects

Two Ss were run, one for 10 sessions (TB) and one for 14 sessions (WG). They were draftsment supplied by a contractor, and they performed as part of their regular duties. Each S reported having 20/20 vision.

Apparatus

The control and timing apparatus employed was the same as in the previous experiments. Four displays were used. The first, denoted by S, arranged the letters of the alphabet, except M and V, in order in a horizontal line. This display is shown in Figure 7.

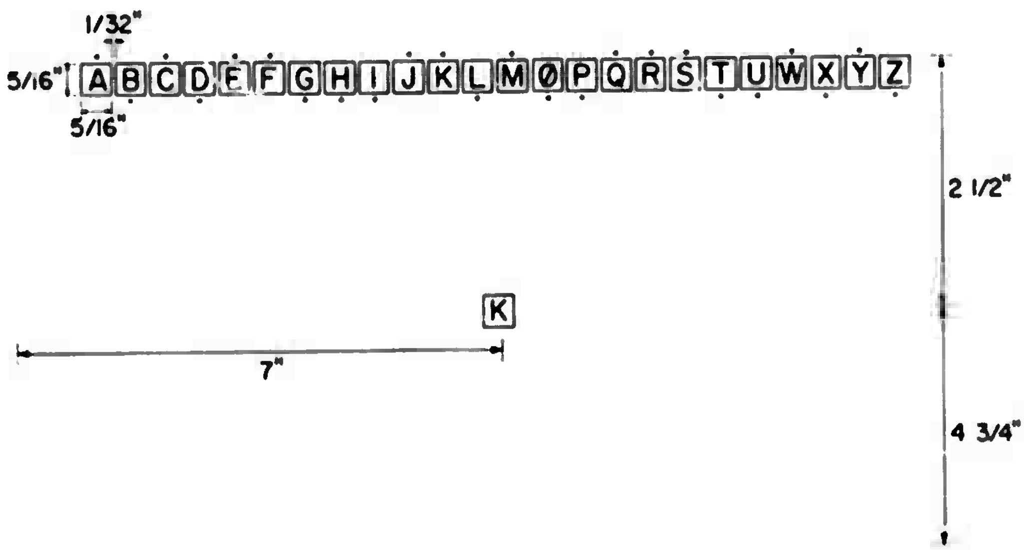

Fig. 7. Display S.

The average distance of the letters from the warning box on this line display was 3.25 in. The straight line format was adopted rather than the semicircular format used in the previous experiment to eliminate differences in verticality as a cue which S could use to remember object locations. The hope was to thereby enhance response time differences between this display and the second display. The second display, denoted by P, for partition, arranged these letters in the same configuration as that used for P in Experiment II (see Figure 4). The average distance of the letters from the warning box was 3.76 in. While the average distance between the two displays was different, the discrepancy should, if anything, have favored performance on Display S. The Ss sat approximately 18 in. from the display.

Each letter on these displays was surrounded by a box. The purpose of the boxes was to reduce the contribution of idiosyncratic letter features by making the visual appearance of the targets more homogeneous. The letter sizes and the dot to letter distances were the same as in the previous experiments. The remaining two displays, denoted by S' and P', were constructed from S and P by replacing the letters on these displays with asterisks. Otherwise, S' and P' were isomorphic to S and P.

Procedure

The procedure was basically the same as in the previous experiments. Each S worked with both Display S and Display P on every session. On the first and on every subsequent third session, the Ss ran three blocks of 60 trials each on Displays S and P, and one block of trials each on S' and P'. S' always followed the three blocks on S, and P' always followed the three blocks on P. On the intervening sessions, the Ss ran

four blocks of trials each on S and P. The order of presentation of S and P was balanced within each subject across the experiment.

Results

Both Ss made fewer than 5% errors. Subject TB made 1% errors on Display S and 2% errors on Display P. Subject WG made 2% errors on both displays. The response time results are presented in Figures 8 and 9 which plot mean response time for all displays and percent errors for P' and S' over sessions. The data points for the error curves are only for those sessions in which S' and P' were administered. The vertical bars represent plus and minus one standard error of the mean. Both Ss became significantly faster on Display P than on Display S as is evidenced by the separation between means of more than two standard errors. A separation this large is equivalent to a t test significant at the 0.05 level. This finding replicates the results of Experiment II.

Performance on P' was far superior to S', with respect to both response time and percent errors. The procedure of replacing the letters with asterisks showed that memory for target location was far superior for Display P', so much so that at least one S (WG) operated on memory alone almost as efficiently as he did with the letters present. Subject WG also performed as well on Display P' as he did on Display S. Thus, the grouped display allowed him to operate as well on the basis of memory alone as he did on the other display when the letters were present.

The figures also show that memory task improvement corresponded with response time improvement on Displays S and P. Subject TB, with practice, became faster on both Displays S' and P' and became more accurate on Display S'. Subject WG reduced both his response time and

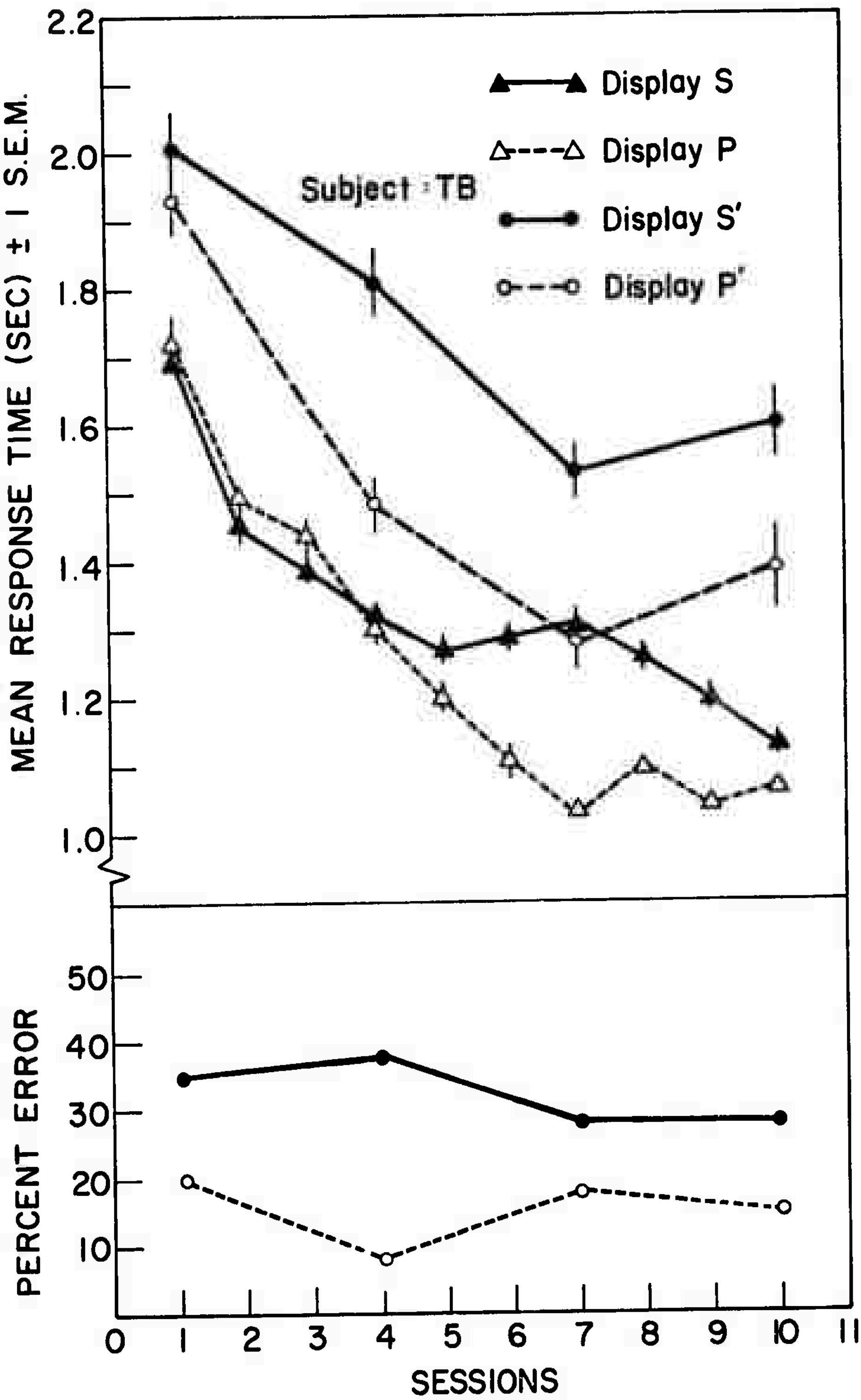

Fig. 8. Mean response time and percent error.

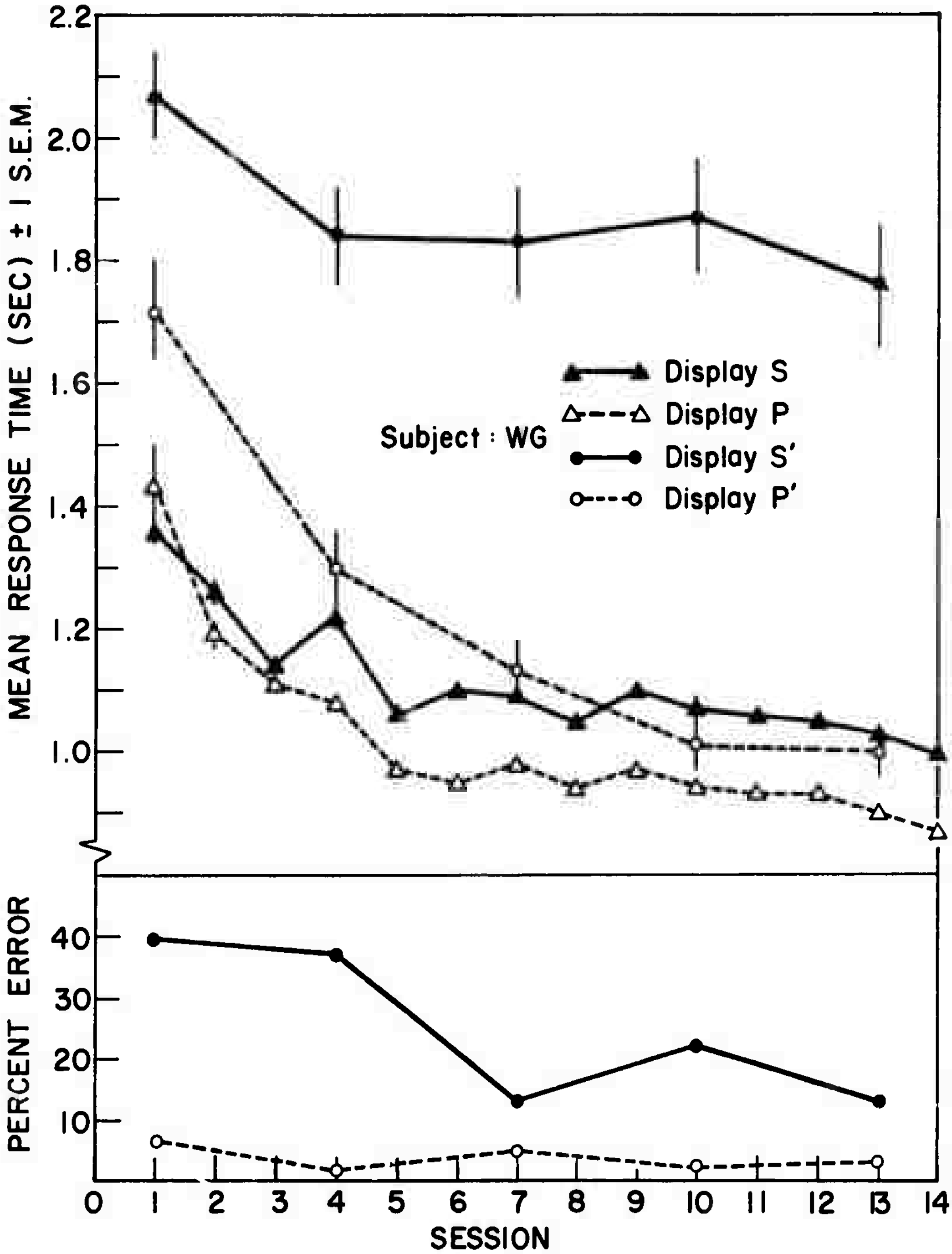

Fig. 9. Mean response time and percent error.

percent error on Display S' and consistently maintained a low error rate while markedly reducing his response time on Display P'.

The data for the last two sessions on Display P were analyzed by a two-way analysis of variance with one observation per cell, representing letter mean response time. The variables were Ss and letters. The letters' variance was partitioned into variance between groups of letters and residual variance. The Ss variable, the letters variable, and the groups within letters variable were each significant at the 0.05 level (see Table 27 in the Appendix).

Linear contrast analysis of the groups within letters variance showed a significant difference in response time between the left and right halves of the display ($\overline{RT}$ = 0.94 sec and $\overline{RT}$ = 1.00 sec, respectively). This result is the reverse of the corresponding result in Experiment II. In that experiment, Ss responded faster to the right half of the display. Linear contrasts also failed to reveal any differences either between letter groups as a function of the number of items they contained ($\overline{RT}$ = 0.97 sec for both sizes) or as a function of the distance of the rows from the warning box ($\overline{RT}$ = 0.97 sec for all the rows). The former result replicates the corresponding result in Experiment II, but the latter result does not. Thus, for the Ss in this experiment, response time did not vary as a function either of letter group size or of distance from the warning box.

Since the distance result was somewhat surprising, three orthogonal posterior linear contrasts were performed on the letter group means (see Table 27 in the Appendix). A Scheffe decision rule criterion was used to test significance; each of these contrasts was significant at the 0.05 level. The contrasts taken together accounted for 100% of the

groups within letters variance. The contrasts partitioned the letter group mean response times into four sets (slowest to fastest) which were homogeneous within a set and heterogeneous between sets. Inspection of each S's data for these sets only revealed a strong S by letter interaction, i.e., one S's mean response time to a particular letter would be much slower or much faster than his overall mean response time to all the letters; the other S's data sometimes corresponded and sometimes did not correspond.

The change to using a straight line format for the unpartitioned display (S) permitted many more comparisons across displays between letter pairs whose distances from the warning box differed by no more than 0.2 in. Forty-four such comparisons were made on letters' mean response times for the last two sessions. Subject TB responded as quickly or more quickly to the letters on Display P on 86% of the comparisons, and Subject WG responded as quickly or more quickly to the letters on Display P on 89% of the comparisons. While some of this effect might have been due to differences in time to read the letters in the warning box, it is heartening to note that the single comparison which involved the same letter on both displays, the letter J, showed the same result. Both Ss responded more quickly to the letter J on Display P than on Display S. Thus, partitioning the visual field by grouping the targets enhances search speed when target distances are roughly equal.

Experiment IV

The results of Experiments I, II, and III, although they support the worth of the proposed approach, are restricted to a few Ss and to the letters of the alphabet. The alphabet itself is an ordered set of

symbols and is well known. The proposed approach would be more general if the previous results could be extended to another, less well known, symbol set. In addition to examining the generalizability of the approach, this experiment was designed to extend prior results showing that different geometrical arrangements of the same symbols lead to differential memory strengths in learning the symbol locations.

One specific way to strengthen this conclusion is to compare performance difference scores. Suppose that S's memory is interrogated at different times for the locations of objects on the display by requiring him to perform his usual task with another corresponding display, one on which all the objects have been replaced with empty boxes. Then for each object two performance scores can be compared, one for when the object is present and one for when the object is absent. The mean for these difference scores for all objects on the display gives a single number to measure how well this S performs on this display when he must rely on memory alone as compared with how well he performs when the objects are available to him in the visual field.

If there is another display, then, of course, a mean difference score for this S on that display can similarly be obtained. Two mean difference scores for this S, one mean difference score for each display, now exist and can be compared by subtracting one from the other. A final measure between the two displays thus exists which measures how well this S performs on the basis of memory alone as compared with how well he performs when the objects are present in the visual field. This final measure for each S can be obtained, and results can be averaged to yield a grand mean difference score.

Since the original performance scores were obtained by sampling the Ss' behavior at different times, this grand mean difference score gives us a measure of differences in strength of memory for object locations for objects arranged in different geometric configurations across practice. If there is no difference in memory strength between two configurations, then the grand mean difference score will not differ significantly from zero. Otherwise, it will.

The two independent variables were 1) geometric arrangement of the symbols, and 2) symbols present or absent; response time was the dependent variable.

Subjects

Eight Ss served from a paid subject pool. All were male undergraduates at the University of Michigan. Each reported his vision as 20/20.

Apparatus

The apparatus consisted of a Digital Equipment Corporation PDP 1 computer, a Standard Proctor and Equipment Co., Inc. Model 750 Automatic strip film projector for 35 mm strip film, and four aluminum response boxes, each housing two Minneapolis-Honeywell Regulator Co. 3 pole BZ-2RD Microswitches. The strip film projector was 106 in. from a wall, and presented the display upon the wall.

Four displays were used. The first, denoted by S, arranged 12 arbitrary symbols in a horizontal line, as is shown in Figure 10. The numbers in this figure refer to the actual sizes of the projected images on the wall. The dot size was 1/8 in. in diameter, and each dot was situated above or below each box by 1/16 in. The second display, denoted by P, arranged these same symbols in four groups of three symbols each. This is shown in Figure 11. The remaining two displays, S' and P', were

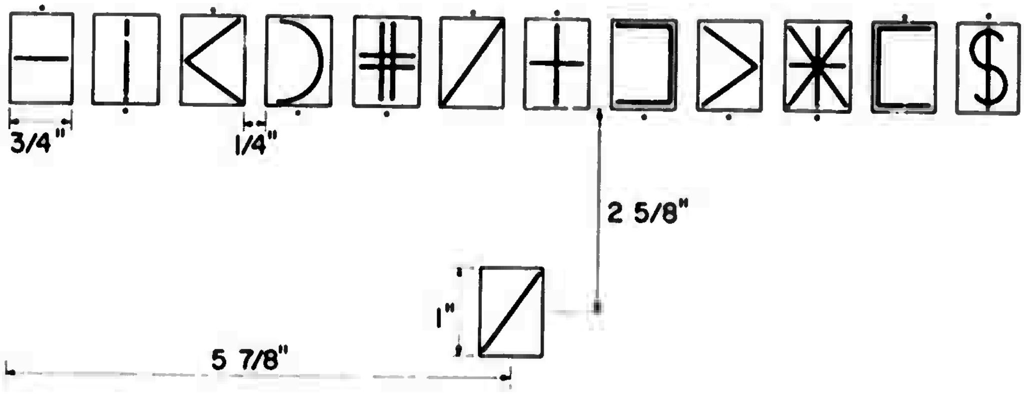

Fig. 10. Display S.

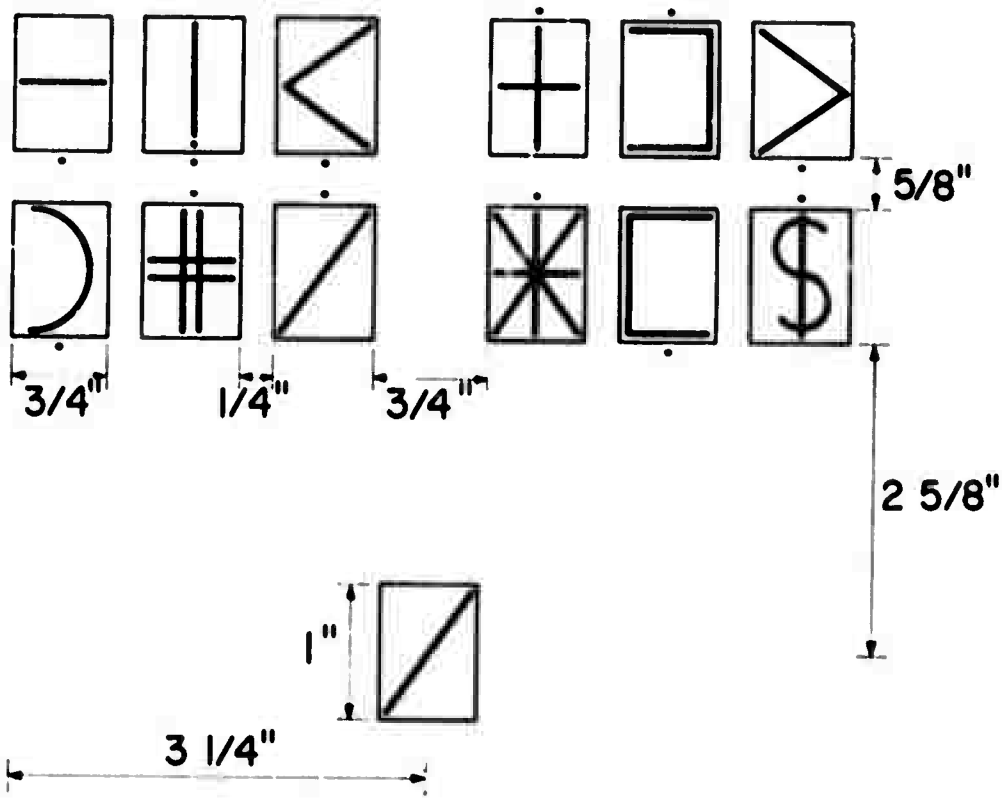

Fig. 11. Display P.

constructed from S and P by removing all symbols from them, leaving only the boxes. The symbol below the layout in each display designated the target to be found. The average symbol distance from this box was constant in all displays.

Procedure

The Ss were run in two groups of four each for 14 sessions. They sat about a table, in a darkened room, each with his response box in front of him. Two Ss sat approximately 48 in. from the wall, and two sat approximately 90 in. from the wall.

The S's task was the same as that in the previous experiments. The Ss were instructed to perform at no more than a 5% error rate. To reinforce this instruction, Ss were told that the two fastest men in each group would be paid a bonus at the end of the experiment, if they had not exceeded the 5% overall error rate. Each individual's total number of errors and average response time were posted on the following day. Response omissions were scored as errors.

On each trial, the computer advanced the film strip and presented a stimulus frame for 3 sec. After all Ss had responded, the film strip was advanced two blank frames (for a total of 2 sec) and then advanced to the next stimulus frame. If a S did not respond within the 3-sec time limit, he was given additional time, but his response was scored as a 3-sec error. This happened very infrequently.

Each group worked with both Display S and Display P on every session. On the first and on every subsequent third session, the Ss ran three blocks of 60 trials each on Displays S and P, and one block of trials each on S' and P'. S' always followed the three blocks on S, and P' always followed the three blocks on P. On the intervening sessions, the

Ss ran four blocks of trials each on S and P. The order of presentation of S and P was balanced within each group across the experiment, and was reversed between the two groups.

Results

So many data were generated in this experiment that the results of only two Ss, Subject 4 and Subject 8, will be presented here. The data for all the Ss are presented in the Appendix. Most Ss operated at or below the 5% error level on Display S and on Display P, with a range of 1% to 5% error on each display. Subject 2, however, operated at the instructed error level only through the first 11 sessions. On the last three sessions, however, he operated at an 8% to 15% error level. The average error rate over all Ss was 3% for Display P and 3% for Display S. Figures 12 and 13 plot mean response time and percent error over sessions. The vertical bars represent plus and minus one standard error of the mean; the vertical bars are sometimes obscured by the triangles and circles on the graphs. Whenever this happens, the standard error of the mean is less than the vertical extent of the triangle or circle (a typical value for the standard error is 0.02 sec). The data for the error curves is only for those occasions in which S' and P' were administered.

These data replicate the findings in the previous experiments: The partitioned display (P) with practice produced faster response times than did the straight display (S). Every S showed this effect for at least three consecutive days somewhere in the experiment, usually late in practice. Six of the eight Ss consistently showed the effect over the last three days of practice. The exceptions were Subject 2 and Subject 7 (see Table 2 and Table 7 in the Appendix). Subject 2 did not

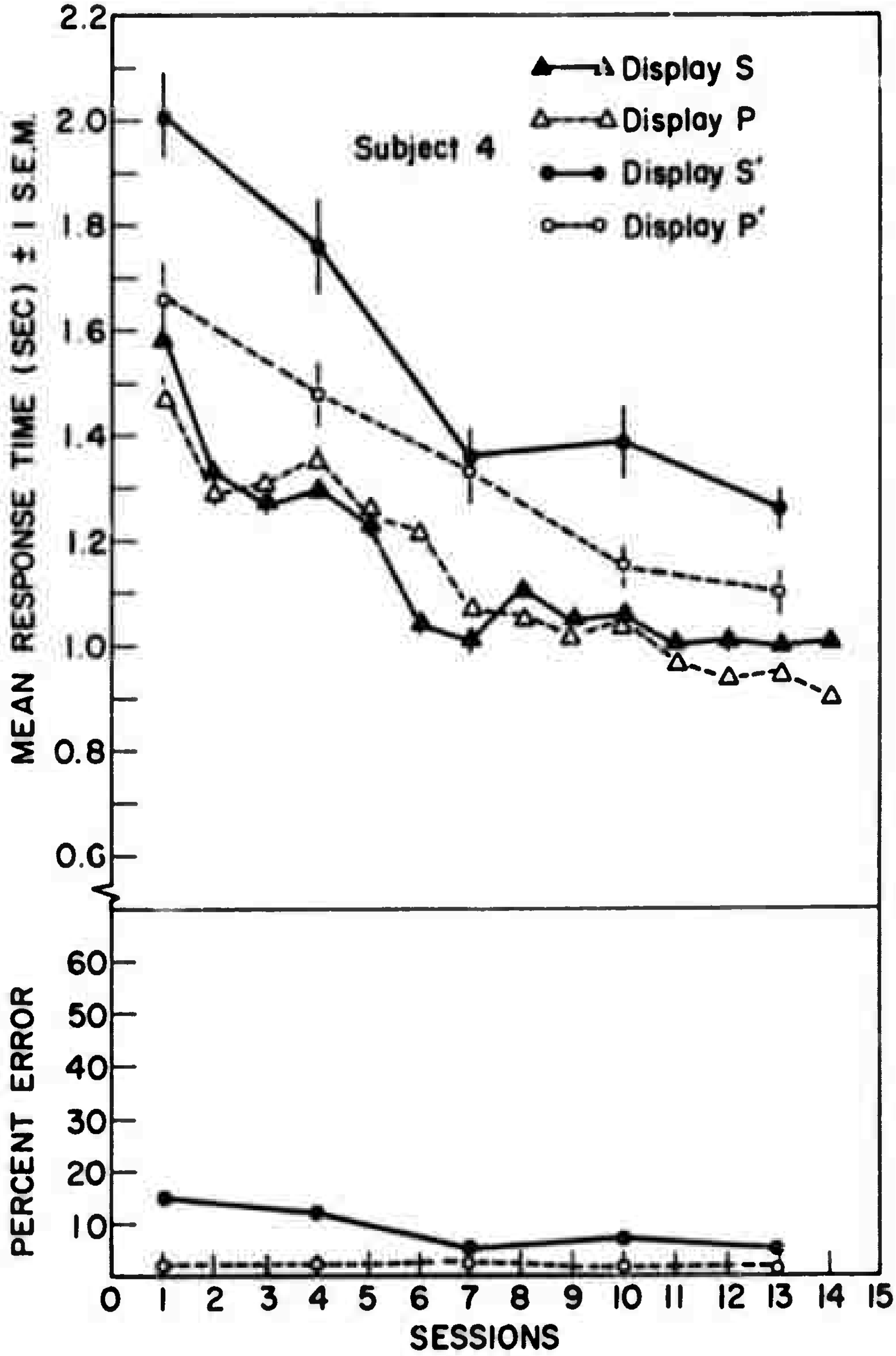

Fig. 12. Mean response time and percent error over sessions.

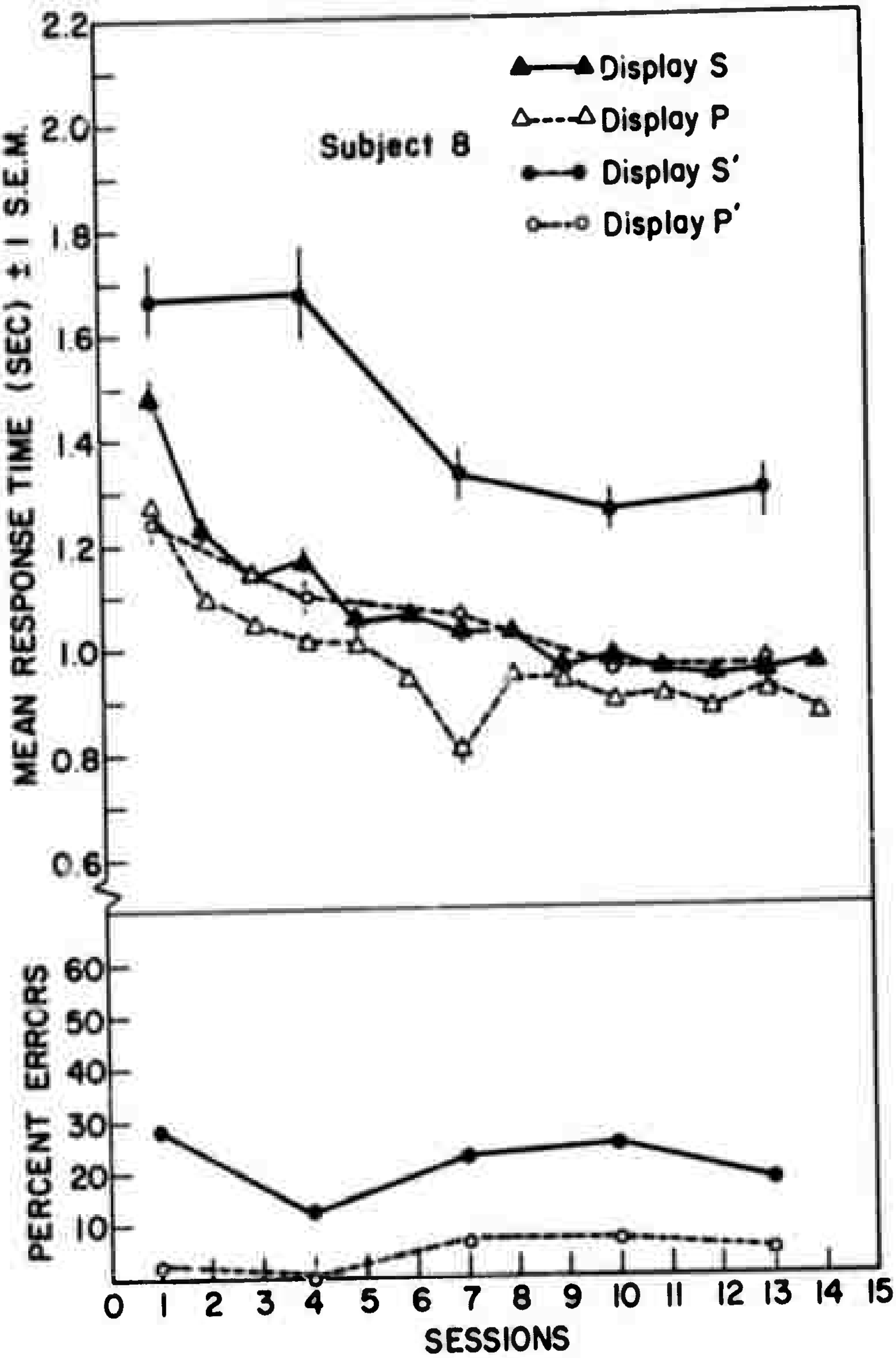

Fig. 13. Mean response time and percent error over sessions.

improve over the last three days of practice on Display P, but he did improve on Display S on the last day. Interpretation of his data for the last three sessions, however, is obscured by the change in error rate to an average of 11% errors for each display. In particular, he made half again as many errors on Display S as on Display P on the last session. Subject 7 showed no significant improvement in performance within either display on the last three days of practice and performed significantly more slowly on Session 13 than on Session 12 on Display P. He did, however, perform significantly faster on Display P than on Display S on Session 14.

If we ignore Subject 2's change in error rate, it might be argued that these two Ss developed equally useful graticules for Display S and Display P, and therefore showed no difference in response time. However, their performance when the symbols were removed from the displays invalidates the argument. Both Ss showed a clear superiority of Display P' over Display S' on Session 13 with respect to both mean response time and percent error. Thus, some unknown variable other than memory for symbol locations must account for the elimination of the previously consistent superiority of Display P over Display S.

With the exception of Subject 2, the difference in mean response time for the last session between Display S and Display P ranged over Ss from 70 msec to 100 msec. The size of this difference is about the same as the sizes of the differences obtained in the previous experiments. Two major differences, however, between the present and the earlier results are the amount of practice necessary to produce the effect between Display S and Display P, and the number of times the curves crossed in the response time plots. In general Ss took much

longer to show consistently the response time effect between Displays S and P in this experiment than Ss did in the previous ones, although once again there were marked individual differences. One S showed the effect throughout the experiment (Subject 6) while another S consistently showed the effect only on the last three days of the experiment (Subject 3).

The number of times the RT curves crossed is a single measure of the variability of the RT difference between Display S and Display P. For example, Subject 4 in Figure 12 showed a switch between Session 7 and Session 8. In general Ss oscillated much more in this experiment than in the previous ones, but there were wide individual differences. Subject 6, for example, had no switches while Subject 3 had eight switches (see Table 3 and Table 6 in the Appendix). A change from a well-known ordered symbol set of 24 items to an unknown unordered symbol set of 12 items yielded, with practice, approximately the same results for response time in graticular search, but more practice was required and more variability in the RT effect was shown.

Removing the symbols from the displays produced several interesting effects. The first was that performance on P' became superior to performance on S'. This superiority indicates that Ss learned symbol locations better when the symbols were grouped than they did when the symbols were ungrouped. The second result was that improvement in performance on the memory task corresponded with improvement on the reference task. Thus, Ss developed more useful graticules as they became more proficient on the reference task. The third result was that as they became more practiced, Ss responded on the memory task either faster or more accurately or both. There was no evidence, however, for

a speed-accuracy tradeoff whereby Ss responded more accurately by responding more slowly or more inaccurately by responding more quickly. Finally, individual differences were very apparent, both in the overall accuracy and manner of responding. Thus, some Ss showed the superiority of P' over S' for both response time and percent error, whereas other Ss with practice responded approximately as accurately on both displays (0% to 7% error) but more slowly on Display S'. These individual differences support the contention that given the same stimulus configurations, Ss can and do develop different graticules.

Figures 14 and 15 present mean response time over symbol positions for both displays early and late in practice. The left half of the figures presents Display P, while the right half presents Display S. The upper half of the figures presents the means for Days 1 to 4, while the lower half presents the means for Days 10 to 13. Each symbol is indicated below its corresponding response time. Each mean is composed of 70 observations.

Note that practice did not equally affect performance for each symbol and that the effect of practice depended on the layout of the display. Particularly for Display S, the most marked improvement came at the ends and toward the middle of the display. The marked improvement at the ends of the display replicates the response time gradient found in the previous experiments.

Figures 16 and 17 present a comparison of the response times for all the displays over practice. The left half of each figure presents the partitioned displays, while the right half of each figure presents the straight displays. The upper half of each figure presents the Symbols-Absent Condition, while the lower half of each figure presents

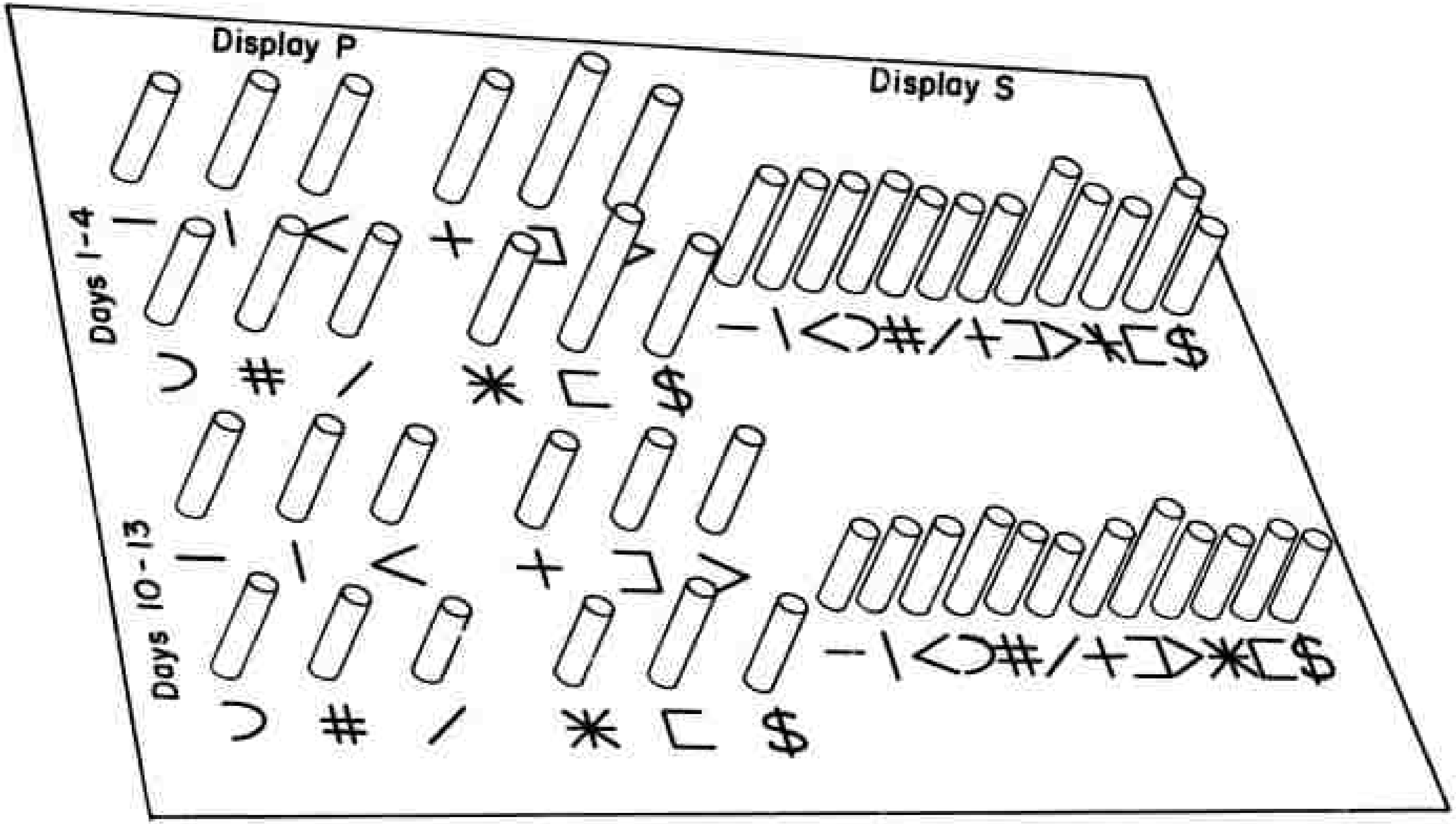

Fig. 14. Change in mean response time (sec) over practice. Data from Subject 4.

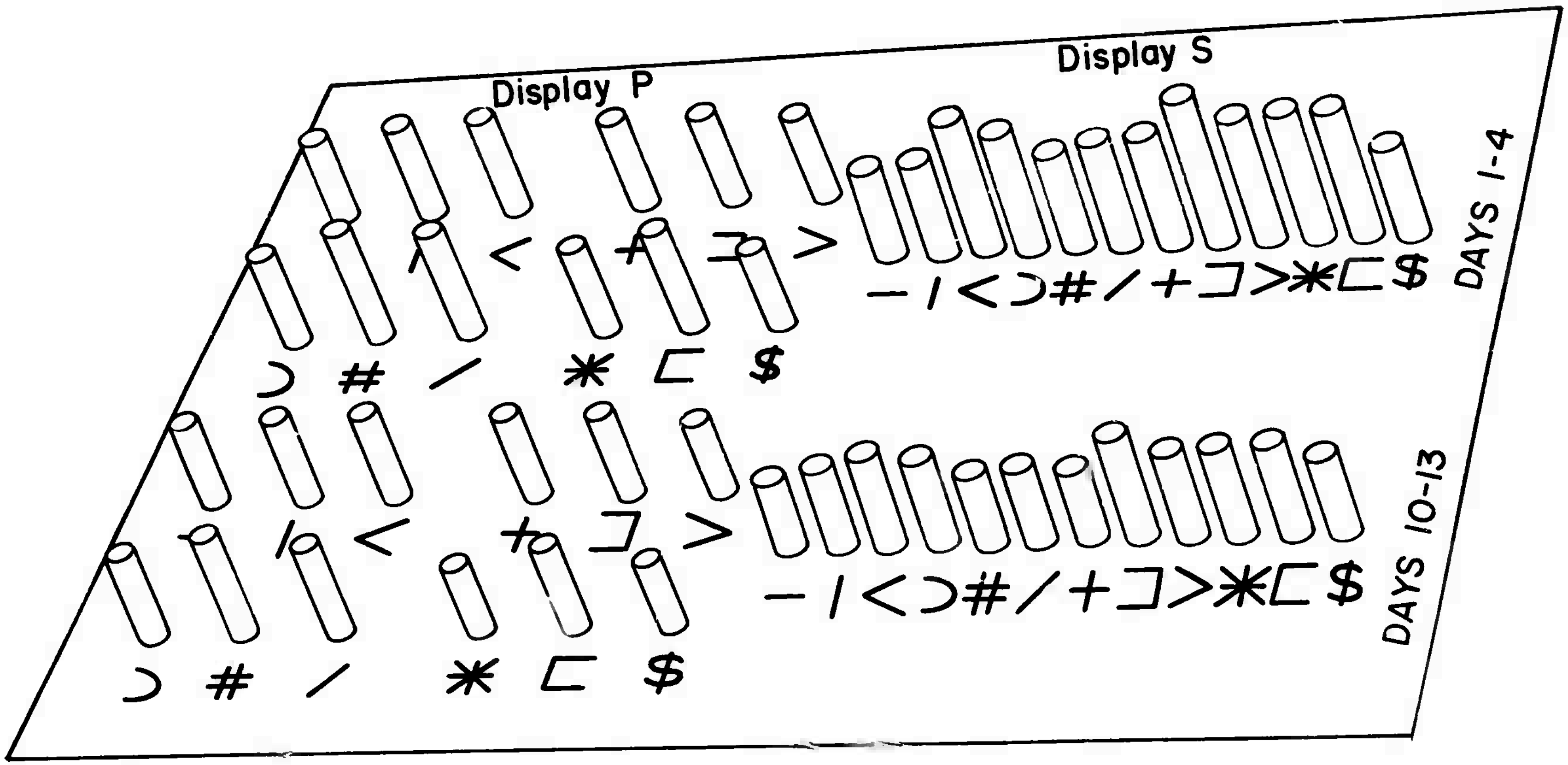

Fig. 15. Change in mean response time (sec) over practice. Data from Subject 8.

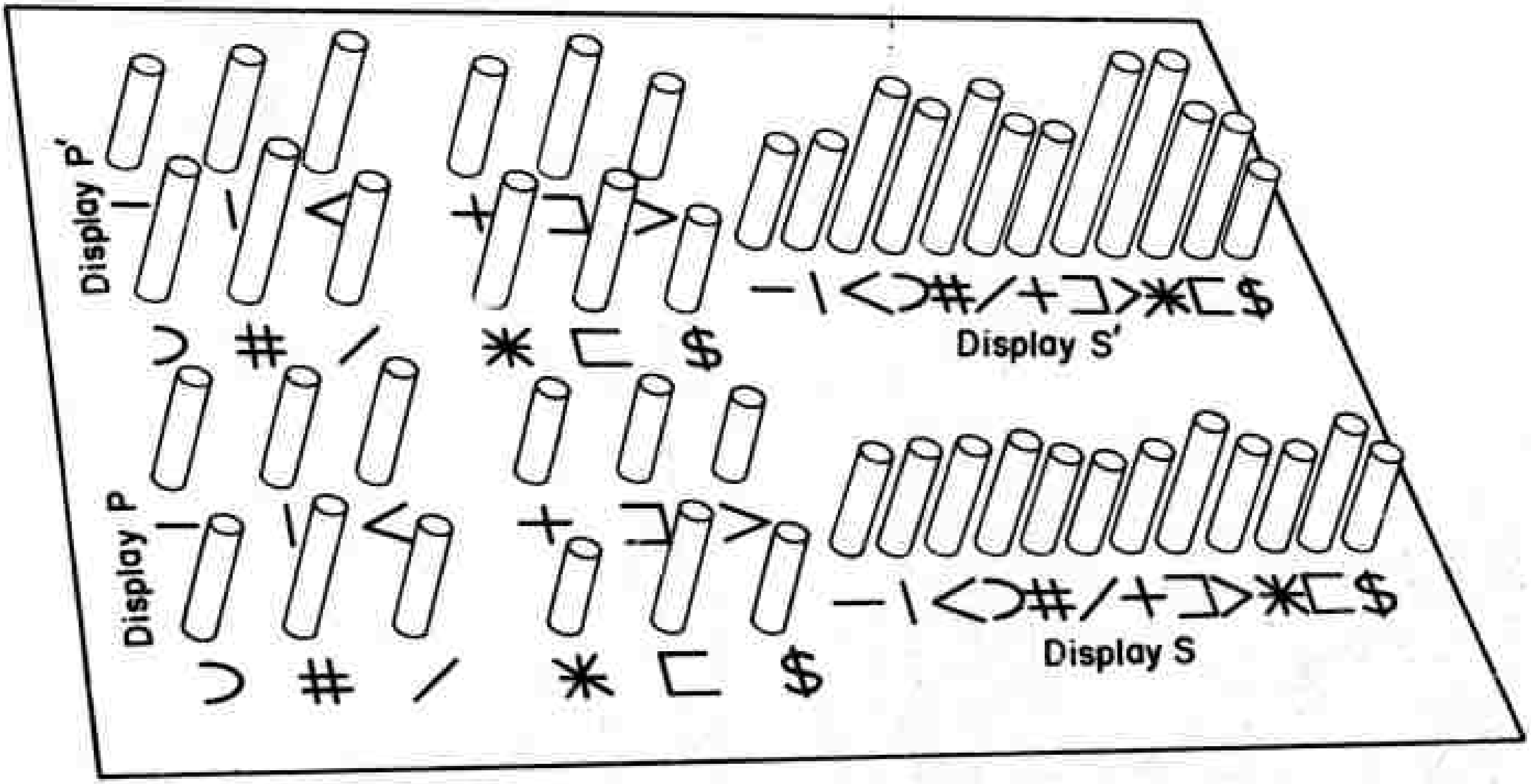

Fig. 16. Mean response time (sec) for symbols present and absent. Data from Subject 4.

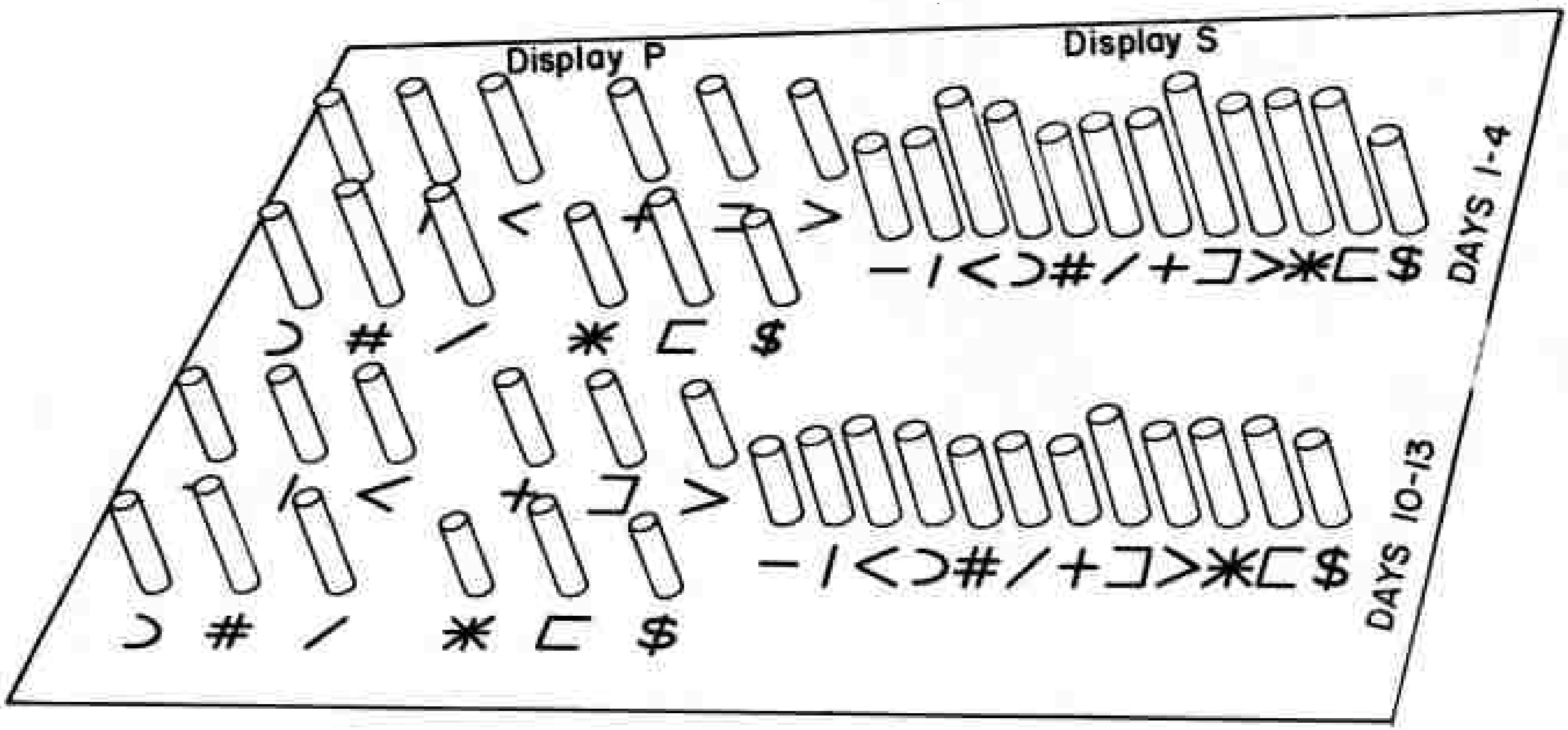

Fig. 15. Change in mean response time (sec) over practice. Data from Subject 8.

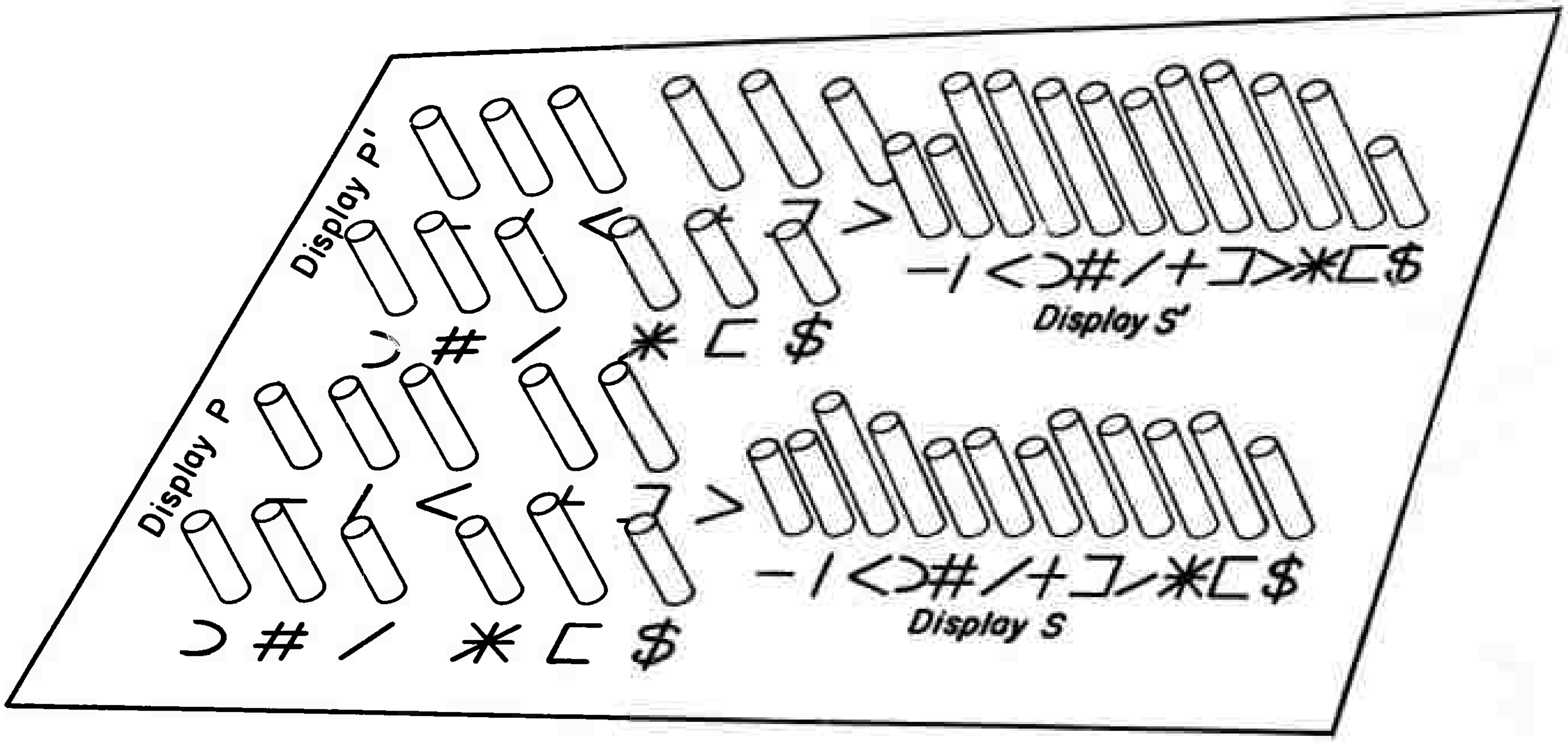

Fig. 17. Mean response time (sec) for symbols present and absent. Data from Subject 8.

the Symbols-Present Condition. Each mean response time represents 25 observations. The data for S' and P' represent the pooled observations gained from the five administrations of each of these displays. The data for S and P result from pooling the numbers for the single block of trials just preceding each administration of S' and P'. These numbers thus compare the displays over equivalent practice.

Response time with the symbols present is faster than when the symbols are removed, indicating that Ss experience greater subjective uncertainty for symbol location when a visual check is lacking; more importantly, because it shows differential memory strength in learning symbol locations, the difference in response time for a given symbol between the symbol present and absent conditions depends on the layout of the display. In general, the response time differences for symbols in P' and P are smaller than the response time differences for symbols in S' and S.

The following procedure was used to test this interaction effect: For each Symbol i and Subject j, the difference in mean response time on Displays P'_{ij} and P_{ij} was subtracted from the difference in mean response time on Displays S'_{ij} and S_{ij}. This is represented symbolically by $Y_{ij} = (S'_{ij} - S_{ij}) - (P'_{ij} - P_{ij})$ where Y_{ij} is the difference between difference scores for each Symbol i and Subject j. This was done for all symbols and Ss, and then a two-way Analysis of Variance was computed with symbols and Ss as the variables, and the Y_{ij} score as the one observation per cell.

The critical question for this analysis is whether the grand mean for Y_{ij} scores (0.24 sec) differs significantly from zero. This analysis is given in Table 25 in the Appendix. The mean square for interaction

was used as an estimate of the error variance. The grand mean differed significantly from zero at the 0.05 level with a t value of $t = 14.12$. The data therefore supported the interaction hypothesis that the difference in response times for symbols when they were present and absent was greater for the memory unaided display. The conclusion to be drawn is that memory strength for symbol locations depends on the grouping of the symbols in the visual field.

The RT data for Display P for Days 10 through 13 were analyzed to obtain a more precise idea of how Ss used the grouping arrangement. The data were analyzed by two-way analysis of variance, with Ss as one variable and symbols as the other variable; since Subject 2 violated the permissible error rate, his data were excluded from the analysis.

The Ss, symbols, and Ss x symbols interaction effects were all significant at the 0.05 level (see Table 28). Orthogonal prior linear contrasts on the symbols effect showed significant differences ($p < .05$) between the upper and lower rows ($\overline{RT} = 1.01$ sec and $\overline{RT} = 0.93$ sec, respectively) and the left and right halves ($\overline{RT} = 0.94$ sec and $\overline{RT} = 1.00$ sec, respectively) of the display.

If we denote the outer two symbols in each group of three symbols as the "flanks" and the center symbol as the "middle," then a third prior orthogonal linear contrast showed faster response times for the flanks ($\overline{RT} = 0.94$ sec) than for the middles ($\overline{RT} = 1.03$ sec).

Corresponding analyses of variance were performed on the RT and error data for Display P' for Days 10 and 13 combined. The analysis of the error data showed a significant S effect ($p < .05$) but nonsignificant symbol and symbol x S interaction effects. The overall error rate was 9% (see Table 29). The analysis of the RT data showed significant S and

symbol effects ($p < .05$) and a nonsignificant S x symbol interaction (see Table 30). Prior orthogonal linear contrast analyses of the symbol effect showed the same results obtained previously: The lower row was faster than the upper row (1.10 sec and 1.17 sec, respectively), the left half was faster than the right half (1.10 sec and 1.17 sec, respectively), and the flanks were faster than the middles (1.11 sec and 1.20 sec, respectively).

The correspondence of the response time results for Displays P and P' is both heartening and suggestive. First, it suggests that the way Ss look for targets in graticular search, for a given level of practice, is to use their knowledge about the visual field to delineate portions of the visual field to serve as starting points for search. In particular, the finding that response times to the flanks is faster than the middles both when the symbols are present and when they are absent suggests that when Ss search for a middle target they sometimes look first to one of the flanks and then to the middle target. This interpretation permits us to reject the idea that Ss initially use their knowledge about the visual field to delineate an area in which to perform a random search. Clearly, Ss make more use of their knowledge than that idea would indicate.

Second, the correspondence of the response time results suggests that we can eliminate a single check interpretation to explain why visual search time was a function of the row distance of a target from the warning box. This finding could have resulted from Ss checking the first row for the target when searching for a target which actually belonged in the second row. However, since visual search time in this experiment was a function of the target's row distance both when the

target was visually present and when it was absent, it appears unreasonable that Ss checked the first row for the presence of the target when no targets were visually present at all. The single check interpretation thus becomes untenable.

A more likely explanation of this result is that Ss sometimes used peripheral vision to examine some letters in the lower row while they were looking at the warning box and consequently reduced their average search time. For those Ss who sat 48 in. from the display, the distance to the farthest symbol in each row was approximately five and six degrees from the warning box, while the distance to the nearest letter in each row was four and six degrees. These figures are for the nearest and farthest row, respectively. For those Ss who sat 90 in. from the display, the corresponding figures were two and three degrees, and two and three degrees, respectively. The magnitude of the difference between maximum and minimum visual angle is admittedly small, one to two degrees, but nevertheless might have been large enough to permit Ss to capitalize on it by sometimes extracting information peripherally while looking at the warning box.

Experiment V

One previous experimental result yet to be discussed is that search time was significantly slower when the symbols were removed from the displays. What activity occupied the additional time is a puzzle. If Ss used their knowledge about the visual field to delineate where to look and then looked, what they were looking for when the symbols were missing is unclear. What is clear is that Ss did use their knowledge about the visual field in some respect since they performed the dot judgment task at much better than chance accuracy. One possibility is

that Ss used their knowledge several times perhaps either to count subvocally to the appropriate box or to construct images of the targets in their appropriate locations.

Another possibility is that Ss used a dual strategy, depending on whether the symbols were present or absent. When the symbols were present they could have used the prosence of the symbols as a confirmatory check on whether they had looked correctly. When the symbols were absent so was the check. The Ss therefore adopted the strategy of doing something else when the symbols were missing. In particular, they did not use their knowledge about the visual field to delineate where to look. Rather they engaged in some other unknown but time-consuming activity. This view suggests that evon when the visual field is well known, Ss do that something else when tho symbols are absent and so require more time. Specifically visual search time for four well-known targets should be slower when the targets have been removed. This experiment was designed to test this prediction.

Subjects

Fifteen male undergraduate Ss at the University of Cincinnati served as part of a course requirement. Each S reported his vision as normal.

Apparatus

A back-projection slide system was used in a well-illuminated quiet room. A Kodak Carousel Auto-Focus 850 slide projector presented slides onto a frosted glass rear projection screen. The timing requirements were controlled by three timers, a Hunter Model III-C Series D Decade Interval Timer, and two Electromed Decade Interval Timers, Model TIII. One of those pulsed a Vincent Associates External Shutter Model 2250

which was mounted before the slide projector. The shutter controlled the onset of the slide image on the screen, and opened with a rise time of approximately 5 msec. A Standard Electric Time Model S-I Clock began timing when the external shutter opened. The clock stopped, the shutter closed, and one of two differently colored response signal lights glowed when S pressed one of two Minneapolis-Honeywell 3 pole BZ-ZRD Micro-switches housed in a chassis. The S sat, with a response box in front of him, at one end of a long table. The rear projector screen was mounted 22 in. from him. The E and the remaining equipment were located at the other end of the table, and were screened from S's view.

Two displays were used, Display S and Display S'. Each display was sufficiently bright for easy visibility. Display S contained four targets, the letters A, B, C, and D, arranged in alphabetical order in a row. These particular targets were used because the letters of the alphabet, particularly at the beginning, are well known. Four items are well within immediate memory span. Futura Medium 48-point Letraset letters were used. The projected image sizes were 3/8 in. high and 3/8 in. wide at their maximum. Each letter was centered in and surrounded by a square border whose maximum height and width was 13/16 in. and whose minimum height and width were 10/16 in. A dot 1/8 in. in diameter appeared equally often either above or below each box; the dot was centered horizontally and was separated from the outer perimeter of the box by 1/32 in. An additional identically dimensioned box was located midway horizontally and 13/16 in. (from the lower edge of the row to the upper edge of the box) below the row of four letters. Each of the letters A, B, C, and D appeared singly equally often in the box. Display S' was

constructed from Display S by removing all the letters from the row. Otherwise S' was isomorphic to S.

Eighty slides were made for each display. Forty of these were placed in one Carousel tray and 40 in another. Each group of 40 constituted a block. There were thus four blocks altogether, two for S and two for S'. Within each block each letter was used as a target equally often. The letter presentation order was randomized separately once for each block, and was then fixed. Within each tray the S block always preceded the S' block.

Procedure

The procedure and S's task were basically the same as in the previous experiments. Each S served individually. He was shown a diagram of the displays and the task was explained to him. Any questions he then asked were answered before proceeding. Each S was instructed to respond as quickly as possible while committing no more than two errors per block of trials, a 5% error rate. The mapping of dot position (above and below) to response keys (right and left) was balanced across Ss. No feedback was given, but Ss often commented when they made mistakes. The E said "Ready" to indicate the beginning 80 trials, consisting of a block on Display S followed immediately by a block on Display S'. The E said "Switch" following the Display S block to signal the S that the next slide would be the first of a block of S' trials. On each trial E logged S's response and response time and manually reset the clock. The intertrial interval was constant at 5 sec. The S was given a 5 min rest period following the first 80 trials. During this period E switched the two Carousel trays to prepare for the final set of 80 trials. The order

of Carousel tray usage was balanced across Ss. Each experimental session lasted no more than 45 min.

Results

The first set of 80 trials was considered as practice; consequently, only the data for the second set of 80 trials were analyzed, one block each on Display S and Display S'.

The average error rate for both Display S and Display S' was 4% each. Thus, Ss responded on the average within the instructed error rate. The response time data were analyzed by three-way analysis of variance, with Ss, displays, and letters as the variables. There were 10 observations per cell. The analysis revealed a significant difference ($p < .05$) between the letters, but no significant difference between Display S ($\overline{RT} = 1.04$ sec) and Display S' ($\overline{RT} = 1.02$ sec) (see Table 30). Thus, for the admittedly small amount of practice and small number of letters these Ss experienced, there was no evidence to support the dual strategy hypothesis. Since the first few letters of the alphabet are a well-known set in the population of Ss sampled, it seems unlikely that further practice would have yielded such support. While the major result of this experiment allows us to rule out the simple version of a dual strategy hypothesis for a small letter set, it does not suggest any explanation of the activities Ss engaged in when they used additional time in the memory interrogation task of the previous experiments. This finding remains a puzzle.

CHAPTER III

SUMMARY AND CONCLUSIONS

All the experiments were based on the distinction made between random and graticular search; each experiment investigated an aspect of graticular search. Experiment I showed that it is possible to obtain a response time gradient in a search task in which motor variables have been avoided. Experiment II showed that, a) grouping objects in the visual field speeded visual search as contrasted with search for a non-grouped set of objects, and b) search time is in part a function of object distance from a common starting point.

Experiment III replicated the grouping effect found in Experiment II. Additionally, it demonstrated the following: 1) Improvement on the reference task corresponded with improvement on the memory interrogation task, 2) Performance on the P' display was superior to performance on the S' display, both for speed and accuracy, and 3) The Ss found objects which were grouped faster than they found objects which were not grouped, when the distances of the objects from a common starting point were roughly equal.

Experiment IV extended the results of Experiment III to another less well-known symbol set, and demonstrated again that grouping speeded search time, that improvement on the reference task corresponded with improvement on the memory task, that performance on P' was superior to performance on S', and that the response time gradient is a replicable phenomenon. Experiment IV also showed that grouping objects in the visual field differentially affects memory strength with which objects' locations are learned. The experiment additionally demonstrated that

visual search time for the grouping arrangement used was, a) faster to the lower row than to the upper row, b) faster to the left half than to the right half, and c) faster to the outer two members of a group of three objects than to the middle member, for both Display P and Display P'.

Experiments II, III, and IV all yielded an additional puzzling finding, namely, that performance when the symbols were removed was slower in general than performance when the symbols were present. The puzzling aspect is the question of what Ss were doing during the additional time. Experiment V examined the hypothesis that when the symbols were present Ss used their knowledge about the visual field to decide where to look and then looked, but when the symbols were absent Ss did something else which required more time. Experiment V showed that visual search time for a small well-known target ensemble was equally as fast when the symbols were absent as when they were present.

Certain limitations to these results should be noted. One limitation is that the only independent variable manipulated has been grouping of the objects in the visual field. Williams' (1966) data, however, suggest that Ss impose a preference ordering on the cues they use in visual search when several cues are available. Color in particular was the most strongly preferred and utilized cue, and could easily be used as a means of partitioning objects in the visual field. Size and shape are other useful cues. All these cues could be used in a graticular search task, singly and in combination, to determine their effects. One question, for example, is whether color coding is a better cue than grouping in reducing search time.

A second limitation of the research was the lack of interpretation of errors. The Ss may have committed errors either because their eyes landed on an incorrect object, or because they could not remember where to go next, or both. Presumably, greater physical separation between objects would reduce the first type of error. The present research did not systematically vary physical separation in order to investigate this question. However, since the overall error rates were low, since there were no differences in error rates between the partitioned and the unpartitioned displays (P and S) in any of the experiments, and since the comparisons between displays were typically made within a S, the results of the experiments remain clear.

Perhaps the most important limitation on the results is the limited amount of practice used. There was no strong evidence that Ss had reached a steady state level of learning and performance; the response time differences between the grouped and nongrouped displays obtained in these experiments might well disappear with additional practice. The slope values of 40 to 50 msec per item found in Experiment I are consonant with scanning rates found in memory search tasks, and suggest that Ss at least part of the time use letter order to find targets. Grouping the targets generally produced a savings in search time of 100 msec; this figure is equivalent to the savings which would be realized if the size of the positive set in a high-speed memory scanning task were reduced by three items (Sternberg, 1966). The 100 msec figure was obtained in two situations, one with 24 letters of the alphabet on display and one with 12 arbitrary symbols on display. If the overlearned nature of the alphabet permitted Ss to reject almost immediately half the alphabet as irrelevant, then perhaps the size of an effective

positive set for the alphabet and for the arbitrary symbols might have been equivalent. Nevertheless, nothing in the data forces such a conclusion, and too much should not be made of what is probably a coincidence. It seems reasonable, however, that sufficient practice could overcome the slower rate of learning object locations found with a nongrouped set so that eventually performance would equal that for a grouped set of objects.

The purpose of this dissertation was to begin to investigate gıaticular search so that a more complete theory of visual search, rather than a theory based only on random search, could begin to be developed. An approach which, while simple, accounted for the available related data and served to guide the conduct of inquiry was that Ss develop idiosyncratic mappings of stable visual fields which they use when searching for targets. The Ss adjust their graticules with experience, and use cues such as grouping in looking. Arrangement provides one or more cues to use in looking; differing arrangements provide different numbers of cues. In particular, a grouped arrangement provides more cues than a nongrouped arrangement. The greater number of cues provided by a grouped arrangement allows Ss to develop better graticules and thereby to find targets faster.

The picture which emerges from these results is that in a graticular search task Ss develop idiosyncratic graticules which they adjust with practice. The Ss improve in visual search speed at least in part because they develop better graticules. They use their graticules to delineate where to look and look, perhaps alternating between deciding where to look with looking. Within a particular arıangement of objects in a stable visual field, Ss learn certain objects and their locations

better than they do others; these differences in memory strength are reflected in differences in search speed, even when the objects are equally distant from a common starting point. Between differing arrangements of the same objects, Ss learn the objects' locations better for a grouped arrangement than for a nongrouped arrangement. Once again the difference in overall learning is reflected in a difference in search speed. Finally, even within the grouped arrangement, Ss learn object locations as a function of position. The Ss seem to use grouping to develop anchor points for search, i.e., they seem to use the flanks of a group to find the middle member of the group since search time to the flanks is faster than to the middles both when the symbols are visually present and absent.

There are two possible objections from the data at hand which might possibly cloud the picture. The first is the finding in Experiment II that search time was a function of the target distance from the warning box. This finding led to the single check hypothesis which was rejected at the time on the basis that Ss could as well have checked the second row of the display while going to the third as the first on the way to the second or third. The replication of the distance finding in Experiment IV might well have revived the hypothesis except that the memory task data showed the same pattern. The data pattern correspondence suggests that the distance result is not due to checking one row while in transit to searching another row, but rather is due at least in part to a memory process wherein the further row is not as well remembered as the nearer. While eye movement records would most easily settle the issue, it seems unreasonable that Ss would check an empty row for a target that is not there. However, the explanation most likely lies in

the visual distances of locations nearest the warning box. On some occasions Ss may have used peripheral vision to extract information about symbols whose locations were nearest the warning box while simultaneously looking at the warning box, and thereby reduced their search times for those symbols. Eye movement records would indicate the extent to which Ss used this strategy.

The second objection is that since much of the picture of what Ss do in graticular search arises from interpretation of the memory interrogation task data, that picture is clouded by the discrepancy in search times between the memory task and the usual task. What additional activities Ss engage in during the longer search times found when the symbols are removed remains a puzzle. The result in Experiment V that search time for a small, well-known symbol set was equally as fast when the symbols were present as when they were absent suggests that the additional time requirements of the previous experiments are not an artifact of the experimental technique wherein Ss adopt a different strategy altogether when the symbols are removed. While the yet to be discussed key to when the discrepancy appears may well lie in the nature and particularly in the number of objects in the visual field, one reasonable approach to its existence is to suppose that Ss use the presence of the objects as a confirmatory check that they have looked correctly. When the objects are absent they engage in some activity to serve as a substitute check, an activity which is in addition to using their knowledge about the visual field to delineate where to look and then looking. While the additional activity might be to count to the location, to construct images of the targets in their locations, to re-reference their graticules, or whatever, clearly, Ss would spend less time in

substitute checking the more certain they were of the target's location. Since grouping produced better knowledge about object locations, we could expect that Ss substitute check less either in number of checks or time per check or both with a grouped display and consequently that the magnitude of the search time difference when symbols were present and absent would be smaller for the grouped display. The analysis of difference scores in Experiment IV support this expectation, but we should remain wary of what is after all an *ad hoc* explanation. Future research is required.

These experiments meanwhile have practical implications for the design of displays and control panels. In any large system, once the system analysis has been completed, system functions are allocated among components in such a way as to minimize some overall cost function equation. Man quite often serves as an interface between other men and machines. Since operator response time clearly enters into the overall cost function, minimization of the cost function benefits by minimization of operator response time.

Man quite often functions in a system as a decision maker. In order to perform this function, the man monitors information displays which present the current state of different system components. These displays often use lights as indicators of components' states. For example, an energized light might represent telephone call traffic overload in a particular switching machine, and the man might want to shunt some of these calls via another machine. He would then desire to examine the current state of the second switching machine. The present experiments imply that grouping the lights on the displays and grouping

the displays is one way to speed the decision maker's search time. He could then initiate a directive to an operator.

The operator's function as an interface between the decision maker and a machine is to receive massages from a manager and to execute the specified actions by pressing appropriate control panel buttons. The experiments reported here clearly delineate visual search as a component of the task, and show that grouping objects in the visual field is one way to speed search time.

Suppose that the system analysis has produced a priority ordering, either in terms of action frequency or action value, on the actions the operator can implement, and suppose that the operator implements each action by pressing one pushbutton. While the overall implication of the present experiments is that pushbuttons should be grouped, Experiments II and IV result that search time, at least for some Ss, varies as a function of object distance suggests that those high priority pushbuttons should be placed close to the operator's starting point. If space limitations for some reason preclude grouping the pushbuttons, the high priority actions should be placed at the ends of the pushbutton array.

The strong individual differences among Ss also have implications for the selection and training of operators. Clearly men should be selected who respond both quickly and accurately, or who can be trained to do so. All the present experiments imply that Ss given the same stimulus configuration can and do develop different graticules. Future research should investigate how Ss develop graticules and how they use them.

Several questions, just in the domain of grouping targets as the experimental manipulation, remain as topics for future research. Some

are listed below: What should be the size of the objects? Within a group, what should be the minimal separation between objects? Should objects be grouped with respect to some common characteristic, varying the characteristics between groups? How should objects be arranged within a group? Should objects within a group be the same size, shape, color, brightness; i.e., physically visually homogeneous? What is the maximum number of groups people can remember within the visual field? Does this number change as a function of practice? What is the maximum number of objects within a group that people can easily remember? Does this number change with practice? Do number of groupings and number of items per grouping interact? If so, how? Once one has fixed the number of objects per group and the number of groups, how should one place the objects in the visual field? Is there some optimum placement? How do eye movements vary as a function of target distance from a starting point? How do Ss' graticules correspond with the visual field? How are graticules developed? Given that a S has a graticule, how does he use it, in parallel, serially, exhaustively, etc.?

The last questions require some speculation about the nature of graticules. In the broadest sense a S's graticule is his knowledge about a stable, experiential world based on encoded representations of events which occur both in space and time. While some psychologists would refer to this knowledge as a cognitive map, the term map unfortunately connotes spatiality and thereby limits our scope. We have therefore used graticule instead because it more easily allows us to incorporate the temporal domain. A S uses his graticule as a tool to delimit where to look and thereby reduces the size of the possibility space he considers. For example, in a dial reading task employing a continuous

scale dial with a pointer, successive short illuminations of the dial allow the S to reduce successively the neighborhood in which he looks about the pointer. The successive illuminations thereby function as a type of graticule built up temporally.

Since so little is known about graticules, what is required are techniques for investigating them. One technique to investigate graticules for visual displays is to add an object to a well-learned display, for example, to add an additional object to just fill the gap between the two groups in the upper row of Display P in Experiment IV (see Figure 11). The question is whether the additional object would disrupt performance. Under one view there should be no disruption since the object locations are well learned. The S must merely learn another object and its location. Under another view disruption would occur because the grouping arrangement provided cues which the S learned to use in searching and the insertion of the additional object removed those cues. The latter view seems more intuitively reasonable than the former and suggests that the S would need to reorganize his graticule. Whatever the actual outcome of this thought experiment might be, the technique is one example of what is needed to examine the nature of graticules.

This is only one of the problems remaining to be examined in graticular search. This dissertation makes the posing of this and other related problems possible by, 1) pointing to a neglected area of visual search, that of graticular search, and 2) suggesting an approach by which relevant data can be understood, experiments generated, and results explained. Although this approach is tentative, as all first

approaches must be, five experiments have tested aspects of it and suggest that it is a useful initial attempt to explain systematically an important aspect of visual search.

APPENDIX

TABLE 1

SUMMARY DATA OVER SESSIONS

MEAN RESPONSE TIME (SEC) AND STANDARD ERROR

OF THE MEAN (SEC)* - SUBJECT 1

Session	Display P	Display S	Display P'	Display S'
1	1.40 .04	1.30 .03	1.55 .07	1.56 .06
2	1.20 .02	1.29 .03		
3	1.19 .02	1.20 .02		
4	1.16 .02	1.14 .02	1.28 .06	1.51 .06
5	1.08 .01	1.22 .02		
6	1.02 .01	1.11 .02		
7	1.04 .01	1.15 .02	1.19 .05	1.49 .06
8	1.14 .02	1.17 .02		
9	1.20 .02	1.30 .03		
10	1.20 .02	1.20 .02	1.43 .07	1.57 .07
11	1.12 .02	1.22 .03		
12	1.00 .02	1.10 .02		
13	1.01 .02	1.04 .02	1.07 .06	1.23 .05
14	1.00 .02	1.07 .03		

Per-Cent Error for Memory Tests

Session	Display P'	Display S'
1	22	38
4	3	33
7	3	0
10	7	12
13	12	15

*The standard error is the lower figure in each box

TABLE 2

SUMMARY DATA OVER SESSIONS

MEAN RESPONSE TIME (SEC) AND STANDARD ERROR

OF THE MEAN (SEC) - SUBJECT 2

Session	Display P	Display S	Display P'	Display S'
1	1.61 .03	1.91 .04	1.67 .06	2.08 .07
2	1.49 .02	1.68 .03		
3	1.40 .02	1.77 .03		
4	1.43 .03	1.55 .03	1.46 .05	2.14 .09
5	1.43 .02	1.51 .03		
6	1.36 .02	1.21 .02		
7	1.12 .02	1.15 .03	1.22 .04	1.78 .09
8	1.13 .01	1.19 .02		
9	1.08 .02	1.11 .01		
10	1.08 .01	1.20 .02	1.16 .04	1.48 .07
11	1.01 .01	1.06 .02		
12	.97 .01	1.06 .01		
13	1.03 .02	1.06 .01	1.12 .03	1.41 .06
14	.96 .01	.97 .02		

Per-Cent Error for Memory Tests

Session	Display P'	Display S'
1	3	50
4	2	28
7	7	23
10	5	8
13	8	17

*The standard error is the lower figure in each box.

TABLE 3

SUMMARY DATA OVER SESSIONS

MEAN RESPONSE TIME (SEC) AND STANDARD ERROR

OF THE MEAN (SEC) - SUBJECT 3

Session	Display P	Display S	Display P'	Display S'
1	1.57	1.65	1.57	2.14
	.03	.03	.05	.08
2	1.50	1.44		
	.02	.02		
3	1.51	1.51		
	.02	.03		
4	1.47	1.41	1.49	1.85
	.03	.03	.06	.08
5	1.30	1.34		
	.02	.02		
6	1.29	1.15		
	.02	.01		
7	1.10	1.10	1.36	1.44
	.01	.01	.06	.07
8	1.13	1.16		
	.01	.01		
9	1.12	1.07		
	.02	.01		
10	1.11	1.20	1.30	1.65
	.02	.02	.06	.07
11	1.12	1.09		
	.01	.02		
12	1.08	1.13		
	.02	.02		
13	1.07	1.11	1.21	1.50
	.01	.02	.03	.06
14	1.03	1.12		
	.01	.01		

Per-Cent Error for Memory Tests

Session	Display P'	Display S'
1	2	20
4	2	8
7	2	3
10	3	13
13	3	5

*The standard error is the lower figure in each box.

TABLE 4

SUMMARY DATA OVER SESSIONS

MEAN RESPONSE TIME (SEC) AND STANDARD ERROR

OF THE MEAN (SEC) - SUBJECT 4

Session	Display P	Display S	Display P'	Display S'
1	1.49 .02	1.60 .02	1.67 .06	2.01 .08
2	1.29 .02	1.33 .02		
3	1.31 .02	1.27 .02		
4	1.36 .02	1.30 .02	1.48 .06	1.76 .09
5	1.25 .02	1.23 .02		
6	1.22 .02	1.04 .01		
7	1.07 .02	1.01 .02	1.33 .06	1.36 .05
8	1.06 .01	1.11 .01		
9	1.02 .01	1.05 .01		
10	1.05 .01	1.06 .02	1.15 .04	1.39 .07
11	.97 .02	1.00 .01		
12	.94 .02	1.01 .02		
13	.95 .01	1.00 .01	1.10 .04	1.26 .04
14	.91 .01	1.01 .01		

Per-Cent Error for Memory Tests

Session	Display P'	Display S'
1	2	15
4	2	12
7	3	5
10	2	7
13	2	5

*The standard error is the lower figure in each box.

TABLE 5

SUMMARY DATA OVER SESSIONS

MEAN RESPONSE TIME (SEC) AND STANDARD ERROR

OF THE MEAN (SEC) - SUBJECT 5

Session	Display P	Display S	Display P'	Display S'
1	1.32 .02	1.73 .04	1.37 .05	1.99 .08
2	1.21 .02	1.30 .02		
3	1.16 .02	1.25 .01		
4	1.21 .03	1.31 .02	1.29 .06	1.72 .08
5	1.14 .02	1.14 .02		
6	1.08 .01	1.16 .01		
7	1.13 .02	1.20 .03	1.12 .03	1.68 .08
8	1.05 .01	1.12 .01		
9	1.14 .02	1.14 .02		
10	1.06 .01	1.13 .01	1.08 .03	1.49 .06
11	1.04 .02	1.06 .01		
12	1.00 .01	1.10 .01		
13	1.03 .01	1.08 .02	1.08 .04	1.49 .06
14	1.01 .01	1.11 .01		

Per-Cent Error for Memory Tests

Session	Display P'	Display S'
1	5	27
4	5	22
7	2	10
10	3	10
13	0	7

*The standard error is the lower figure in each box.

TABLE 6

SUMMARY DATA OVER SESSIONS

MEAN RESPONSE TIME (SEC) AND STANDARD ERROR

OF THE MEAN (SEC) - SUBJECT 6

Session	Display P	Display S	Display P'	Display S'
1	1.27 .03	1.74 .04	1.34 .06	1.85 .06
2	1.09 .01	1.24 .03		
3	1.04 .01	1.19 .02		
4	1.04 .02	1.18 .03	1.08 .03	1.55 .08
5	.95 .01	1.08 .01		
6	.96 .01	1.06 .01		
7	.99 .01	1.05 .02	1.07 .03	1.33 .06
8	.98 .01	1.03 .01		
9	.94 .01	.99 .01		
10	.87 .01	.95 .01	.90 .02	1.01 .04
11	.88 .01	.93 .01		
12	.84 .01	.96 .01		
13	.93 .01	.97 .01	.99 .02	1.14 .04
14	.87 .01	.95 .01		

Per-Cent Error for Memory Tests

Session	Display P'	Display S'
1	12	40
4	0	43
7	2	22
10	5	22
13	20	35

*The standard error is the lower figure in each box.

TABLE 7

SUMMARY DATA OVER SESSIONS

MEAN RESPONSE TIME (SEC) AND STANDARD ERROR OF THE MEAN (SEC) - SUBJECT 7

Session	Display P	Display S	Display P'	Display S'
1	1.17 .02	1.48 .03	1.27 .06	1.51 .06
2	1.08 .02	1.16 .02		
3	1.02 .01	1.11 .01		
4	1.00 .01	1.07 .02	1.00 .01	1.38 .07
5	.96 .01	.98 .01		
6	.93 .01	1.00 .01		
7	.97 .02	1.02 .02	.98 .01	1.22 .05
8	.92 .01	.97 .01		
9	.90 .01	.92 .01		
10	.87 .01	.92 .01	.85 .02	1.01 .04
11	.80 .01	.82 .01		
12	.80 .01	.90 .01		
13	.87 .01	.88 .01	.85 .02	1.00 .02
14	.82 .01	.91 .01		

Per-Cent Error for Memory Tests

Session	Display P'	Display S'
1	7	32
4	13	20
7	3	3
10	7	17
13	5	18

*The standard error is the lower figure in each box.

TABLE 8

SUMMARY DATA OVER SESSIONS

MEAN RESPONSE TIME (SEC) AND STANDARD ERROR

OF THE MEAN (SEC) - SUBJECT 8

Session	Display P	Display S	Display P'	Display S'
1	1.27 .02	1.49 .03	1.24 .03	1.67 .07
2	1.11 .01	1.23 .02		
3	1.05 .01	1.14 .01		
4	1.02 .01	1.17 .02	1.10 .03	1.68 .09
5	1.01 .01	1.05 .02		
6	.95 .01	1.06 .01		
7	.80 .02	1.03 .02	1.06 .02	1.33 .05
8	.94 .01	1.03 .01		
9	.94 .01	.96 .01		
10	.90 .01	.98 .01	.96 .01	1.26 .04
11	.91 .01	.95 .01		
12	.88 .01	.94 .01		
13	.92 .01	.95 .01	.96 .02	1.29 .05
14	.88 .01	.97 .01		

Per-Cent Error for Memory Tests

Session	Display P'	Display S'
1	3	28
4	0	12
7	7	23
10	7	25
13	5	18

*The standard error is the lower figure in each box.

TABLE 9

MEAN RESPONSE TIME (SEC), STANDARD ERROR OF THE MEAN (SEC), AND ERROR RATE OVER DISPLAYS EARLY AND LATE IN PRACTICE* - SUBJECT 1

Days 1-4

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.13	.03	.03	1.05	.02	.06
C2	1.09	.03	.06	1.12	.02	.04
C3	1.17	.03	.10	1.20	.03	.04
C4	1.05	.03	.00	1.14	.03	.07
C5	1.04	.03	.04	.94	.01	.01
C6	1.13	.05	.01	1.08	.04	.01
C7	1.49	.06	.07	1.44	.06	.04
C8	1.52	.05	.09	1.49	.05	.07
C9	1.35	.03	.10	1.38	.04	.03
C10	1.12	.03	.03	1.21	.03	.01
C11	1.58	.06	.07	1.72	.06	.04
C12	1.08	.02	.06	1.04	.01	.04

Days 10-13

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.16	.05	.04	1.12	.04	.01
C2	1.16	.04	.04	1.18	.03	.06
C3	1.12	.02	.07	1.21	.03	.01
C4	.93	.02	.03	1.06	.03	.06
C5	.93	.01	.03	.96	.03	.01
C6	.85	.02	.00	.83	.01	.01
C7	1.12	.02	.03	1.16	.04	.01
C8	1.35	.04	.14	1.36	.05	.01
C9	1.20	.04	.01	1.19	.02	.04
C10	.96	.02	.04	1.14	.03	.01
C11	1.23	.05	.01	1.53	.05	.10
C12	.94	[illegible]	.04	.96	.03	.04

*The designations C1...C12 refer to the leftmost to rightmost ordering of symbols on Display S.

TABLE 9

MEAN RESPONSE TIME (SEC), STANDARD ERROR OF THE MEAN (SEC), AND ERROR RATE OVER DISPLAYS EARLY AND LATE IN PRACTICE* - SUBJECT 1

Days 1-4

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.13	.03	.03	1.05	.02	.06
C2	1.09	.03	.06	1.12	.02	.04
C3	1.17	.03	.10	1.20	.03	.04
C4	1.05	.03	.00	1.14	.03	.07
C5	1.04	.03	.04	.94	.01	.01
C6	1.13	.05	.01	1.08	.04	.01
C7	1.49	.06	.07	1.44	.06	.04
C8	1.52	.05	.09	1.49	.05	.07
C9	1.35	.03	.10	1.38	.04	.03
C10	1.12	.03	.03	1.21	.03	.01
C11	1.58	.06	.07	1.72	.06	.04
C12	1.08	.02	.06	1.04	.01	.04

Days 10-13

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.16	.05	.04	1.12	.04	.01
C2	1.16	.04	.04	1.18	.03	.06
C3	1.12	.02	.07	1.21	.03	.01
C4	.93	.02	.03	1.06	.03	.06
C5	.93	.01	.03	.96	.03	.01
C6	.85	.02	.00	.83	.01	.01
C7	1.12	.02	.03	1.16	.04	.01
C8	1.35	.04	.14	1.36	.05	.01
C9	1.20	.04	.01	1.19	.02	.04
C10	.96	.02	.04	1.14	.03	.01
C11	1.23	.05	.01	1.53	.05	.10
C12	.94	.02	.04	.96	.03	.04

*The designations C1...C12 refer to the leftmost to rightmost ordering of symbols on Display S.

TABLE 10

MEAN RESPONSE TIME (SEC), STANDARD ERROR OF THE MEAN (SEC), AND ERROR RATE OVER DISPLAYS EARLY AND LATE IN PRACTICE* - SUBJECT 2

Days 1-4

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.31	.04	.01	1.34	.03	.00
C2	1.40	.04	.00	1.49	.04	.03
C3	1.66	.04	.01	2.11	.06	.07
C4	1.29	.03	.01	1.68	.05	.04
C5	1.40	.03	.00	1.64	.05	.01
C6	1.41	.04	.00	1.90	.06	.10
C7	1.57	.04	.00	1.92	.06	.06
C8	1.79	.03	.00	2.15	.06	.11
C9	1.53	.05	.01	1.73	.05	.01
C10	1.40	.04	.00	1.57	.05	.03
C11	1.69	.05	.01	1.84	.06	.07
C12	1.27	.03	.00	1.36	.05	.01

Days 10-13

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.94	.01	.06	.98	.02	.03
C2	1.05	.02	.10	1.06	.02	.10
C3	1.08	.02	.09	1.17	.03	.06
C4	.95	.01	.10	1.10	.02	.09
C5	.95	.02	.13	.98	.02	.06
C6	.99	.03	.04	1.09	.03	.09
C7	1.07	.02	.07	1.09	.03	.09
C8	1.18	.02	.11	1.36	.03	.11
C9	1.10	.03	.06	1.20	.03	.03
C10	.96	.03	.10	1.12	.03	.04
C11	1.01	.02	.06	1.06	.03	.03
C12	.92	.01	.04	.89	.02	.04

*The designations C1...C12 refer to the leftmost to rightmost ordering of symbols on Display S.

TABLE 11

MEAN RESPONSE TIME (SEC), STANDARD ERROR OF THE MEAN (SEC), AND ERROR RATE OVER DISPLAYS EARLY AND LATE IN PRACTICE* - SUBJECT 3

Days 1-4

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.39	.04	.00	1.33	.03	.00
C2	1.46	.04	.01	1.35	.03	.00
C3	1.45	.03	.00	1.58	.05	.04
C4	1.47	.04	.00	1.47	.04	.00
C5	1.36	.03	.00	1.27	.03	.00
C6	1.33	.05	.01	1.40	.05	.00
C7	1.62	.04	.03	1.31	.07	.00
C8	1.86	.04	.00	1.83	.05	.01
C9	1.62	.04	.01	1.53	.04	.00
C10	1.37	.03	.00	1.70	.05	.01
C11	1.83	.05	.01	1.72	.05	.01
C12	1.40	.03	.00	1.39	.03	.00

Days 10-13

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.05	.03	.03	1.12	.04	.04
C2	1.08	.02	.06	1.11	.02	.00
C3	1.05	.01	.04	1.16	.02	.04
C4	1.16	.02	.03	1.14	.03	.00
C5	1.01	.02	.06	1.00	.02	.03
C6	.97	.02	.04	.99	.02	.03
C7	1.12	.04	.03	.96	.02	.00
C8	1.21	.02	.01	1.40	.03	.00
C9	1.09	.02	.04	1.15	.02	.07
C10	.93	.02	.03	1.15	.02	.01
C11	1.40	.03	.13	1.28	.03	.01
C12	1.07	.02	.07	1.09	.03	.03

*The designations C1...C12 refer to the leftmost to rightmost ordering of symbols on Display S.

TABLE 12

MEAN RESPONSE TIME (SEC), STANDARD ERROR OF THE MEAN (SEC), AND ERROR RATE OVER DISPLAYS EARLY AND LATE IN PRACTICE* - SUBJECT 4

Days 1-4

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.25	.03	.00	1.34	.03	.00
C2	1.30	.03	.00	1.33	.04	.00
C3	1.43	.04	.00	1.42	.03	.00
C4	1.20	.02	.00	1.42	.03	.00
C5	1.26	.02	.00	1.23	.03	.00
C6	1.17	.03	.00	1.24	.03	.00
C7	1.48	.04	.01	1.24	.03	.00
C8	1.74	.03	.01	1.68	.04	.00
C9	1.70	.03	.00	1.38	.03	.01
C10	1.17	.03	.00	1.29	.03	.00
C11	1.59	.04	.01	1.58	.04	.00
C12	1.27	.03	.00	1.21	.02	.00

Days 10-13

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.95	.01	.01	.94	.01	.00
C2	1.00	.02	.03	1.03	.02	.01
C3	1.00	.02	.03	1.04	.02	.00
C4	.97	.02	.00	1.07	.02	.00
C5	.94	.02	.03	.91	.02	.00
C6	.82	.02	.00	.81	.01	.01
C7	1.02	.01	.03	.98	.03	.03
C8	1.15	.02	.01	1.29	.03	.00
C9	1.01	.02	.03	1.07	.02	.01
C10	.80	.01	.00	1.01	.02	.01
C11	1.11	.03	.00	1.07	.02	.01
C12	.91	.01	.01	.96	.03	.01

*The designations C1...C12 refer to the leftmost to rightmost ordering of symbols on Display S.

TABLE 13

MEAN RESPONSE TIME (SEC), STANDARD ERROR OF THE MEAN (SEC), AND ERROR RATE OVER DISPLAYS EARLY AND LATE IN PRACTICE* - SUBJECT 5

Days 1-4

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.12	.02	.01	1.24	.05	.01
C2	1.15	.01	.00	1.39	.05	.04
C3	1.25	.03	.03	1.53	.05	.03
C4	1.13	.03	.00	1.26	.03	.00
C5	1.08	.02	.00	1.14	.03	.00
C6	1.11	.03	.00	1.34	.05	.03
C7	1.38	.05	.03	1.45	.05	.06
C8	1.47	.03	.01	1.53	.07	.01
C9	1.29	.02	.01	1.44	.03	.00
C10	1.11	.02	.00	1.36	.02	.00
C11	1.44	.04	.06	1.65	.05	.04
C12	1.11	.01	.03	1.19	.03	.03

Days 10-13

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.95	.01	.01	1.02	.02	.00
C2	1.05	.02	.01	1.15	.03	.01
C3	1.11	.03	.01	1.13	.02	.00
C4	.96	.01	.00	1.06	.01	.00
C5	.94	.01	.03	.95	.01	.00
C6	.89	.01	.00	1.00	.02	.00
C7	1.08	.02	.00	1.11	.03	.00
C8	1.17	.02	.01	1.35	.03	.00
C9	1.04	.01	.00	1.13	.02	.00
C10	1.06	.04	.00	1.11	.02	.00
C11	1.18	.02	.00	1.12	.02	.00
C12	.95	.02	.00	.96	.02	.00

*The designations C1...C12 refer to the leftmost to rightmost ordering of symbols on Display S.

TABLE 14

MEAN RESPONSE TIME (SEC), STANDARD ERROR OF THE MEAN (SEC), AND ERROR RATE OVER DISPLAYS EARLY AND LATE IN PRACTICE* - SUBJECT 6

Days 1-4	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.99	.02	.00	1.11	.04	.03
C2	1.03	.01	.01	1.23	.04	.00
C3	1.20	.04	.00	1.39	.05	.06
C4	.98	.02	.00	1.23	.04	.00
C5	.93	.02	.03	.92	.01	.01
C6	1.06	.04	.00	1.17	.04	.00
C7	1.22	.05	.01	1.55	.08	.10
C8	1.35	.03	.00	1.80	.07	.11
C9	1.10	.02	.01	1.44	.05	.01
C10	1.10	.03	.00	1.25	.02	.00
C11	1.29	.03	.00	1.69	.07	.06
C12	1.00	.01	.01	1.08	.04	.00

Days 10-13	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.82	.01	.03	.86	.01	.01
C2	.91	.01	.03	.96	.02	.01
C3	.90	.02	.01	1.04	.02	.06
C4	.90	.02	.04	.99	.02	.11
C5	.85	.02	.07	.78	.01	.00
C6	.84	.01	.01	.88	.02	.04
C7	.90	.01	.03	.92	.02	.05
C8	1.02	.02	.11	1.11	.03	.10
C9	.86	.02	.01	1.05	.02	.01
C10	.77	.01	.04	.96	.01	.04
C11	.95	.02	.07	1.01	.02	.04
C12	.82	.01	.01	.86	.02	.01

*The designations C1...C12 refer to the leftmost to rightmost ordering of symbols on Display S.

TABLE 15

MEAN RESPONSE TIME (SEC), STANDARD ERROR OF THE MEAN (SEC), AND ERROR RATE OVER DISPLAYS EARLY AND LATE IN PRACTICE* - SUBJECT 7

Days 1-4

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.00	.02	.01	1.13	.05	.07
C2	1.02	.01	.03	1.19	.03	.00
C3	1.08	.03	.01	1.24	.03	.06
C4	.95	.01	.03	1.04	.02	.01
C5	.94	.02	.01	.99	.04	.03
C6	.94	.02	.06	1.18	.05	.03
C7	1.08	.02	.03	1.20	.06	.06
C8	1.41	.05	.04	1.36	.03	.01
C9	1.08	.02	.07	1.30	.03	.04
C10	.99	.02	.00	1.36	.03	.00
C11	1.29	.05	.14	1.36	.05	.10
C12	.97	.02	.04	.99	.01	.06

Days 10-13

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.79	.01	.03	.82	.01	.03
C2	.87	.01	.06	.93	.02	.10
C3	.86	.01	.03	.98	.01	.13
C4	.80	.01	.03	.87	.02	.04
C5	.76	.01	.04	[illegible]	.01	.00
C6	.80	.02	.06	.81	.02	.03
C7	.84	.02	.11	.80	.01	.03
C8	.88	.04	.06	1.04	.03	.10
C9	.85	.02	.09	.97	.01	.09
C10	.80	.01	.04	.91	.02	.07
C11	.91	.01	.13	.91	.02	.04
C12	.80	.01	.06	.78	.01	.00

*The designations C1...C12 refer to the leftmost to rightmost ordering of symbols on Display S.

TABLE 16

MEAN RESPONSE TIME (SEC), STANDARD ERROR OF THE MEAN (SEC), AND ERROR RATE OVER DISPLAYS EARLY AND LATE IN PRACTICE* - SUBJECT 8

Days 1-4	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.01	.02	.00	1.06	.04	.03
C2	1.12	.02	.01	1.12	.02	.00
C3	1.20	.02	.01	1.49	.06	.01
C4	1.08	.02	.00	1.32	.05	.00
C5	1.04	.02	.00	1.05	.02	.00
C6	.99	.02	.01	1.20	.04	.01
C7	1.25	.04	.03	1.22	.03	.01
C8	1.32	.03	.00	1.56	.04	.00
C9	1.22	.04	.04	1.32	.03	.01
C10	.98	.01	.00	1.29	.03	.00
C11	1.19	.03	.01	1.36	.04	.01
C12	.93	.01	.01	.98	.02	.03

Days 10-13	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.89	.01	.09	.85	.01	.01
C2	.95	.01	.03	.97	.01	.07
C3	.95	.01	.06	1.11	.01	.10
C4	.90	.01	.03	1.00	.02	.01
C5	.87	.01	.03	.82	.01	.01
C6	.79	.01	.00	.88	.01	.01
C7	.96	.01	.09	.80	.01	.01
C8	1.05	.02	.13	1.11	.02	.20
C9	.95	.01	.06	.99	.02	.03
C10	.78	.01	.01	.99	.02	.07
C11	.95	.02	.04	1.09	.02	.01
C12	.79	.01	.03	.85	.01	.01

*The designations C1...C12 refer to the leftmost to rightmost ordering of symbols on Display S.

TABLE 17

A COMPARISON OF PERFORMANCE WITH SYMBOLS PRESENT AND ABSENT* - SUBJECT 1

	Display P'			Display S'		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.19	.07	.08	1.07	.07	.00
C2	1.14	.07	.00	1.16	.04	.08
C3	1.29	.08	.04	1.43	.07	.16
C4	1.13	.06	.00	1.36	.06	.16
C5	1.35	.10	.20	1.56	.10	.44
C6	1.20	.07	.12	1.58	.09	.20
C7	1.39	.12	.12	1.41	.08	.12
C8	1.81	.10	.16	2.07	.13	.40
C9	1.32	.11	.16	1.70	.09	.12
C10	1.22	.07	.04	1.47	.05	.44
C11	1.60	.10	.12	1.60	.09	.20
C12	.99	.05	.12	1.01	.05	.00

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.13	.07	.04	1.06	.05	.08
C2	1.11	.06	.04	1.11	.03	.00
C3	1.08	.04	.04	1.19	.04	.00
C4	.93	.02	.08	1.11	.07	.00
C5	.97	.04	.00	.89	.03	.00
C6	1.00	.07	.00	.91	.04	.00
C7	1.14	.04	.00	1.20	.05	.04
C8	1.33	.05	.20	1.48	.08	.00
C9	1.21	.04	.00	1.27	.04	.04
C10	1.02	.04	.04	1.21	.05	.04
C11	1.33	.08	.00	1.62	.09	.04
C12	1.03	.04	.08	1.00	.02	.04

*C1...C12 as defined in Table 9.

TABLE 18

A COMPARISON OF PERFORMANCE WITH SYMBOLS

PRESENT AND ABSENT* - SUBJECT 2

	Display P'			Display S'		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.20	.09	.08	1.15	.08	.12
C2	1.23	.07	.00	1.17	.05	.08
C3	1.40	.08	.00	1.81	.12	.16
C4	1.17	.06	.00	1.66	.09	.16
C5	1.50	.11	.16	2.33	.11	.56
C6	1.22	.04	.12	2.32	.11	.64
C7	1.41	.08	.04	2.17	.12	.48
C8	1.61	.09	.04	2.09	.10	.16
C9	1.36	.09	.04	2.30	.11	.36
C10	1.36	.11	.04	1.71	.11	.12
C11	1.32	.07	.08	1.45	.12	.16
C12	1.14	.05	.00	1.13	.06	.04

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.21	.08	.00	1.10	.05	.00
C2	1.29	.08	.04	1.25	.05	.04
C3	1.33	.06	.08	1.61	.12	.04
C4	1.10	.04	.08	1.37	.09	.00
C5	1.11	.05	.08	1.20	.06	.00
C6	1.08	.04	.00	1.39	.11	.12
C7	1.26	.05	.00	1.42	.12	.08
C8	1.39	.07	.04	1.55	.09	.20
C9	1.30	.08	.00	1.37	.06	.00
C10	1.11	.08	.04	1.26	.06	.04
C11	1.31	.09	.04	1.42	.13	.04
C12	1.07	.05	.04	1.01	.03	.00

*C1...C12 as defined in Table 9.

TABLE 19

A COMPARISON OF PERFORMANCE WITH SYMBOLS PRESENT AND ABSENT* - SUBJECT 3

	Display P'			Display S'		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.28	.10	.04	1.13	.08	.04
C2	1.37	.09	.00	1.13	.04	.04
C3	1.40	.09	.04	1.70	.11	.04
C4	1.20	.04	.00	1.52	.08	.08
C5	1.50	.09	.04	2.18	.12	.16
C6	1.15	.05	.04	2.01	.12	.20
C7	1.28	.04	.00	2.34	.14	.28
C8	1.81	.12	.04	2.04	.08	.00
C9	1.33	.06	.00	2.00	.09	.24
C10	1.46	.10	.00	1.91	.10	.08
C11	1.70	.09	.08	1.50	.10	.04
C12	1.16	.03	.00	1.15	.03	.00

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.10	.05	.04	1.23	.09	.04
C2	1.16	.04	.00	1.16	.02	.00
C3	1.16	.03	.04	1.36	.08	.04
C4	1.20	.05	.04	1.28	.05	.00
C5	1.13	.05	.08	1.11	.08	.00
C6	1.02	.04	.00	1.15	.05	.04
C7	1.30	.08	.04	1.12	.07	.00
C8	1.49	.08	.00	1.49	.06	.00
C9	1.26	.05	.00	1.26	.12	.00
C10	1.11	.06	.00	1.36	.08	.00
C11	1.52	.09	.08	1.48	.08	.00
C12	1.16	.05	.04	1.23	.07	.08

*C1...C12 as defined in Table 9.

TABLE 20

A COMPARISON OF PERFORMANCE WITH SYMBOLS PRESENT AND ABSENT* - SUBJECT 4

	Display P'			Display S'		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.18	.06	.00	1.14	.06	.00
C2	1.30	.08	.00	1.17	.04	.08
C3	1.53	.11	.00	1.78	.13	.12
C4	1.22	.06	.00	1.57	.10	.00
C5	1.30	.10	.04	1.81	.14	.20
C6	1.19	.08	.00	1.44	.08	.00
C7	1.51	.12	.04	1.55	.10	.08
C8	1.72	.11	.04	2.12	.08	.16
C9	1.41	.11	.04	2.19	.12	.24
C10	1.36	.10	.08	1.56	.10	.04
C11	1.41	.08	.00	1.35	.10	.12
C12	1.04	.04	.00	.97	.03	.00

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.09	.05	.00	1.13	.05	.00
C2	1.19	.05	.04	1.16	.05	.04
C3	1.22	.08	.00	1.22	.05	.00
C4	1.05	.03	.00	1.22	.07	.00
C5	1.05	.04	.04	1.10	.05	.00
C6	.92	.04	.00	1.01	.07	.00
C7	1.20	.04	.00	1.08	.07	.00
C8	1.40	.08	.00	1.43	.06	.00
C9	1.15	.04	.00	1.21	.05	.00
C10	.94	.04	.00	1.14	.05	.08
C11	1.29	.07	.00	1.38	.08	.00
C12	1.09	.05	.00	1.06	.05	.00

*C1...C12 as defined in Table 9.

TABLE 21

A COMPARISON OF PERFORMANCE WITH SYMBOLS PRESENT AND ABSENT* - SUBJECT 5

	Display P'			Display S'		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.07	.03	.00	1.08	.04	.00
C2	1.08	.04	.00	1.24	.08	.04
C3	1.17	.06	.00	1.94	.12	.28
C4	1.04	.04	.00	1.67	.06	.04
C5	1.25	.07	.04	1.88	.12	.28
C6	1.14	.07	.00	1.95	.11	.28
C7	1.18	.03	.00	1.48	.07	.00
C8	1.42	.10	.12	1.97	.11	.28
C9	1.16	.04	.04	2.17	.11	.28
C10	1.28	.10	.04	1.95	.10	.16
C11	1.45	.10	.12	1.72	.14	.16
C12	1.03	.02	.00	1.02	.04	.00

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	1.09	.05	.00	1.05	.04	.00
C2	1.09	.02	.00	1.20	.04	.00
C3	1.29	.05	.00	1.31	.05	.00
C4	1.01	.02	.00	1.24	.04	.04
C5	1.06	.03	.00	1.11	.05	.00
C6	1.02	.02	.00	1.20	.08	.04
C7	1.21	.07	.00	1.23	.05	.04
C8	1.28	.04	.00	1.45	.06	.00
C9	1.16	.03	.00	1.27	.07	.00
C10	1.09	.04	.00	1.20	.04	.00
C11	1.40	.08	.04	1.33	.07	.00
C12	1.09	.04	.04	1.05	.03	.00

*C1...C12 as defined in Table 9.

TABLE 22

A COMPARISON OF PERFORMANCE WITH SYMBOLS PRESENT AND ABSENT* - SUBJECT 6

	Display P'			Display S'		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.91	.03	.00	1.08	.09	.12
C2	.99	.04	.00	1.07	.05	.08
C3	1.16	.06	.12	1.70	.12	.20
C4	1.01	.06	.12	1.33	.08	.56
C5	.92	.03	.00	1.28	.08	.20
C6	.93	.03	.00	1.48	.12	.52
C7	1.21	.08	.12	1.45	.09	.40
C8	1.44	.08	.24	1.69	.10	.32
C9	.99	.03	.00	1.55	.10	.60
C10	1.12	.07	.24	1.46	.11	.60
C11	1.23	.08	.08	1.58	.12	.24
C12	.99	.03	.00	1.05	.06	.04

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.98	.03	.00	.96	.04	.00
C2	1.01	.03	.00	1.10	.07	.00
C3	1.06	.04	.00	1.20	.04	.04
C4	1.01	.04	.00	1.19	.07	.04
C5	.96	.06	.00	.85	.02	.00
C6	.91	.04	.00	1.05	.07	.08
C7	1.01	.05	.04	1.33	.12	.12
C8	1.21	.04	.00	1.53	.12	.08
C9	1.00	.03	.00	1.17	.04	.04
C10	.95	.05	.00	1.09	.04	.00
C11	1.11	.04	.08	1.41	.13	.04
C12	.93	.02	.00	.96	.03	.00

*C1...C12 as defined in Table 9.

TABLE 23

A COMPARISON OF PERFORMANCE WITH SYMBOLS

PRESENT AND ABSENT* - SUBJECT 7

	Display P'			Display S'		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.99	.05	.08	.93	.05	.04
C2	.99	.04	.04	1.00	.07	.08
C3	.96	.06	.00	1.37	.08	.16
C4	.87	.02	.00	1.27	.10	.08
C5	.96	.03	.08	1.31	.11	.24
C6	.87	.03	.00	1.37	.10	.48
C7	.94	.03	.04	1.16	.07	.20
C8	1.32	.10	.16	1.46	.11	.32
C9	1.05	.08	.04	1.41	.07	.32
C10	.99	.08	.04	1.32	.12	.16
C11	1.14	.10	.12	1.19	.07	.08
C12	.91	.02	.00	.88	.03	.00

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.97	.03	.00	.95	.03	.04
C2	1.00	.02	.08	1.05	.04	.04
C3	1.00	.04	.00	1.09	.04	.04
C4	.91	.02	.00	.97	.01	.00
C5	.88	.02	.04	.87	.04	.00
C6	.88	.04	.00	.97	.03	.00
C7	.97	.02	.00	.93	.07	.00
C8	1.10	.05	.00	1.20	.05	.00
C9	.98	.04	.00	1.10	.06	.00
C10	.92	.02	.04	1.10	.05	.00
C11	1.13	.05	.00	1.18	.06	.00
C12	.96	.04	.00	.87	.02	.04

*C1...C12 as defined in Table 9.

TABLE 24

A COMPARISON OF PERFORMANCE WITH SYMBOLS PRESENT AND ABSENT* - SUBJECT 8

	Display P'			Display S'		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.97	.02	.04	1.08	.06	.00
C2	1.05	.04	.00	1.04	.04	.00
C3	1.16	.05	.00	1.67	.11	.16
C4	1.04	.03	.00	1.69	.09	.24
C5	1.05	.03	.12	1.58	.12	.32
C6	.98	.05	.04	1.54	.10	.12
C7	1.16	.04	.00	1.47	.08	.20
C8	1.23	.04	.16	1.67	.10	.44
C9	1.17	.05	.04	1.69	.11	.40
C10	.98	.02	.04	1.54	.10	.32
C11	1.10	.04	.04	1.46	.10	.40
C12	.92	.02	.04	.93	.02	.00

	Display P			Display S		
	Mean	S.E.M.	Error Rate	Mean	S.E.M.	Error Rate
C1	.97	.02	.00	.94	.03	.00
C2	1.02	.03	.00	1.04	.03	.04
C3	1.09	.03	.00	1.45	.11	.08
C4	.97	.02	.00	1.20	.07	.00
C5	1.00	.04	.00	.93	.04	.00
C6	.88	.02	.00	1.02	.06	.00
C7	1.14	.08	.12	.92	.03	.00
C8	1.14	.04	.00	1.29	.05	.08
C9	1.18	.09	.08	1.10	.04	.00
C10	.91	.03	.00	1.10	.05	.04
C11	1.06	.04	.08	1.22	.05	.00
C12	.87	.03	.08	.87	.03	.00

*C1...C12 as defined in Table 9.

TABLE 25

ANALYSIS OF DIFFERENCE SCORES

Source	d.f.	S.S.	M.S.	F
Grand Mean	1			
Subjects	7	.98	.14	4.67*
Stimuli	11	4.35	.40	13.33*
Subjects x Stimuli	77	2.23	.03	

$$t = \frac{.24 - 0.0}{\sqrt{\frac{.03}{96}}} = 14.12^{*}$$

*Significant at .05 level.

TABLE 26

RESPONSE TIME ANOVA AND LINEAR CONTRASTS

FOR THE LAST TWO DAYS OF PRACTICE

ANOVA

Source	d.f.	S.S.	M.S.	F
Subjects	1	0.09	0.090	22.50*
Letters	23	0.41	0.018	4.50*
Groups	9	0.17	0.019	4.75*
Residual	14	0.24	0.017	
Subjects x Letters	23	0.10	0.004	

*Significant at 0.05 level

Linear Contrasts

Groups of 3 vs. Groups of 2	$F_{1,23}$ = 3.50 n.s.
Left Half vs. Right Half	$F_{1,23}$ = 4.50*
Upper Row vs. Middle Row	$F_{1,23}$ = 0.10 n.s.
Upper Row vs. Lower Row	$F_{1,23}$ = 14.50*

TABLE 27

RESPONSE TIME ANOVA AND LINEAR CONTRASTS

FOR THE LAST TWO DAYS OF PRACTICE

ANOVA

Source	d.f.	S.S.	M.S.	F
Subjects	1	0.27	0.270	38.57*
Letters	23	0.32	0.014	2.00*
Groups	9	0.15	0.017	2.42*
Residual	14	0.17	0.012	
Subjects x Letters	23	0.17	0.007	

*Significant at 0.05 level

Linear Contrasts

Groups of 3 vs. Groups of 2	$F_{1,23} = 0.04$ n.s.
Left Half vs. Right Half	$F_{1,23} = 6.31$*
Upper Row vs. Middle Row	$F_{1,23} = 0.01$ n.s.
Upper Row vs. Lower Row	$F_{1,23} = 2.14$ n.s.
QR and WX vs. Remaining Groups	$F_{1,23} = 9.00$**
ABC, DE, KL, and YZ vs. FGH, IJ, NOP, and STU	$F_{1,23} = 7.71$**
KL vs. ABC, DE, and YZ	$F_{1,23} = 6.43$**

**Significant at the 0.05 level by posterior Scheffe test.
QR and WX were the slowest groups; KL was the fastest group.

TABLE 28

DISPLAY P RESPONSE TIME ANOVA AND

LINEAR CONTRASTS FOR SESSIONS 10-13

ANOVA

Source	d.f.	S.S.	M.S.	F
Subjects	6	53.88	8.98	299.33*
Symbols	11	38.90	3.54	14.75*
Subjects x Symbols	66	15.84	0.24	8.00*
Errors	5,796	172.31	0.03	

*Significant at the 0.05 level

Linear Contrasts

Upper Row vs. Lower Row	$F_{1,5,796} = 416.67$*
Left Half vs. Right Half	$F_{1,5,796} = 216.67$*
Flanks vs. Middles	$F_{1,5,796} = 346.67$*

TABLE 29

DISPLAY P' ERROR ANALYSIS FOR

SESSIONS 10 AND 13 COMBINED

ANOVA

Source	d.f.	S.S.	M.S.	F
Subjects	6	3.36	0.56	3.29*
Symbols	11	1.76	0.16	1.23
Subjects x Symbols	66	8.35	0.13	0.76
Error	756	126.10	0.17	

*Significant at the 0.05 level

TABLE 30

DISPLAY P' RESPONSE TIME ANOVA AND

LINEAR CONTRASTS FOR SESSIONS 10 AND 13 COMBINED

ANOVA

Source	d.f.	S.S.	M.S.	F
Subjects	6	12.03	2.00	18.18*
Symbols	11	10.59	0.96	6.86
Subjects x Symbols	66	9.05	0.14	1.27
Error	756	79.74	0.11	

*Significant at the 0.05 level

Linear Contrasts

Upper Row vs. Lower Row	$F_{1,756} = 8.00$*
Left Half vs. Right Half	$F_{1,756} = 8.00$*
Flanks vs. Middles	$F_{1,756} = 12.82$*

TABLE 31

RESPONSE TIME ANALYSIS FOR

DISPLAY S AND DISPLAY S'

ANOVA

Source	d.f.	S.S.	M.S.	F
Subjects	14	14.21	1.02	23.57*
Displays	1	0.19	0.19	1.46
Letters	3	1.01	0.34	4.81*
Subjects x Displays	14	1.81	0.13	2.99
Subjects x Letters	42	2.95	0.07	1.63
Displays x Letters	3	0.13	0.04	1.11
Subjects x Displays x Letters	42	1.61	0.04	0.89
Error	1080	46.53	0.04	

*Significant at the 0.05 level

REFERENCES

Baker, C. A., Morris, D. F., and Steedman, W. C. Target recognition on complex displays. Human Factors, 1960, 2, 51-60.

Egeth, H. E. Parallel versus serial processes in multidimensional stimulus discrimination. Perception and Psychophysics, 1966, 1, 245-252.

Enoch, J. M. Effect of the size of a complex display upon visual search. Journal of the Optical Society of America, 1959, 49, 280-2[illegible]5.

Garvey, W. D., and Knowles, W. B. Response time patterns associated with various display-control relationships. Journal of Experimental Psychology, 1954, 47, 315-322.

Garvey, W. D., and Mitnick, L. L. Effect of additional spatial references on display-control efficiency. Journal of Experimental Psychology, 1955, 50, 276-282.

Gould, J. D. Pattern recognition and eye movement parameters. Perception and Psychophysics, 1967, 2, 399-407.

Gould, J. D., and Schaffer, A. Eye-movement patterns during visual information processing. Psychonomic Science, 1965, 3, 317-318.

Green, B. F., and Anderson, L. K. Color coding in a visual search task. Journal of Experimental Psychology, 1959, 51, 19-24.

Green, B. F., McGill, W. J., and Jenkins, H. B. The time required to search for numbers on large visual displays. Technical Report No. 36, 1953, Massachusetts Institute of Technology, Lincoln Laboratory.

Groth, H., and Lyman, J. A hierarchy of "perceptual usefulness" of geometrical cues in an over-learned dial reading task. Journal of Applied Psychology, 1961, 45, 86-90.

Smith, S. L. Color coding and visual search. Journal of Experimental Psychology, 1962, 64, 434-440.

Smith, S. W. Time required for target detection in complex abstract visual display. Memorandum of Project Michigan 2900-235-R, 1961, The University of Michigan, Institute of Science and Technology.

Sternberg, S. High speed scanning in human memory. Science, 1966, 153, 652-654.

Williams, L. G. The effect of target specifications on objects fixated during visual search. Perception and Psychophysics, 1966, 1, 315-318.

Ziedman, K., and Lyman, J. Effect of variation in task complexity and displayed information on operator performance. Journal of Applied Psychology, 1963, 47, 260-266.

TECHNICAL REPORTS NOT OTHERWISE PUBLISHED

11. Lively, B. L. The Von Restorff effect in very-short-term memory. December 1968.
15. Kamlet, A. S. Processing of sequentially presented signals in information combining tasks. June 1969.
17. Garskof, M. H. The effect of spacing and variation of repetition in short-term memory. August 1969.
19. Du Charme, W. M. A responsive bias explanation of conservative human inference. December 1969.
20. McCormack, P. D. Monitoring eye movements during the learning of paired-associate lists. March 1970.
21. Goodman, B. C. Risky decisions by individuals and groups. June 1970.
22. Wattenbarger, B. L. The representation of the stimulus in character classification. August 1970.
23. Gardner, G. T. Spatial processing characteristics in the perception of brief visual arrays. August 1970.
24. Adams, R. A. S. Interference in short-term retention of discrete movements. September 1970.
25. Armstrong, T. R. Feedback and perceptual-motor skill learning: A review of information feedback and manual guidance training techniques. August 1970.
26. Armstrong, T. R. Training for the production of memorized movement patterns. August 1970.
27. Collins, A. M. The effect of visual stimulus traces on memory. August 1970.
28. Cohen, V. V. R. Short-term memory for quantitative information from three kinds of visual displays. June 1971.
29. Gelfand, H. Organization in free recall learning: Output contiguity and interresponse times as a function of presentation structure. June 1971.
30. Roberts, K. H. An investigation of paraphrasing: The effects of memory and complexity. June 1971.
31. Thomas. J. C. An analysis of behavior in the Hobbits-Orc problem. August 1971.
32. Bennett, I. F. Spatial effects in visual selective attention. August 1971.
33. Bennett, R. W. Theoretical implications of proactive interference in short-term memory. August 1971.

MEMORANDUM REPORTS AFTER 1968

10. Martin, E. Associative interference theory and spontaneous recovery. November 1969.
12. Greeno, J. G. Theoretical entities in statistical explanation. October 1970.
13. Greeno, J. G. Technical and informal theories about mental entities. October 1970.
14. Halff, H. M. The differential effects of stimulus presentation during error- and success-feedback intervals in concept identification August 1971.